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THE SOCIETY OF AUTOMOTIVE ENGINEERS
INC.

1921
TRANSACTIONS
PART I

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TRANSACTIONS OF THE

SOCIETY OF AUTOMOTIVE ENGINEERS

INC.

PART I VOLUME XVI 1921

Papers and Reports Presented at the
Annual Society and Section Meetings

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29 WEST 39TH STREET, NEW YORK CITY

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The Society of Automotive Engineers
INC.

Founded 1905 — Incorporated 1909

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1908.....Thomas J Fay
1909.....Henry Hess (deceased)
1910.....Howard E Coffin
1911.....Henry Souther (deceased)
1912.....Henry F Donaldson (deceased)
1912.....Herbert W Alden
1913.....Howard Marmon
1914.....Henry M Leland
1915.....W H Vandervoort (deceased)
1916.....Russell Huff
1917.....George W Dunham
1918.....Charles F Kettering
1919.....Charles M Manly
1920.....J. G. Vincent

The Society shall not be responsible for statements or opinions advanced in papers or discussions at its meetings * * *
—(*Constitution, paragraph* 54)

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ANNUAL MEETING

OF THE

SOCIETY OF AUTOMOTIVE ENGINEERS

INC.

NEW YORK CITY
JAN. 11-13, 1921

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THE ANNUAL MEETING

It is hard to appreciate fully the part automotive vehicles have in our national life, not to mention the development that is to come in passenger cars; motor trucks; farm, military and industrial tractors; motorboats; aircraft; semi-portable engines; and farm-lighting units. It is clear that the form and extent of use of these are in their infancy. One's mind can grasp only in a general way what will be the manner and effect of the economical design, production, use and servicing of tens of millions of these vehicles. The intellect of a Jules Verne or an H. G. Wells is not adequate for the visualization of what the automotives will be and do.

In the effort to restore that proper economic balance which is essential to national prosperity the automotive engineers will play their full part. That was fully demonstrated at the sessions of the Society held in New York City Jan. 12 and 13, 1921, at which the attendance was over 30 per cent larger than it was at the corresponding sessions of 1920.

It is said that the American farmer produces four times as much food per human unit as the European; he replaces three men by using horse or power-driven machines and decreases the cost materially. Were it not for plows, harrows, rollers, cultivators, seeding machines, trucks, tractors, hay-making tools, harvesters, threshers, gas engines, diggers, dairy machines and appliances and hundreds of other tools and machines, the production of our farms would be one-fourth what it is. The work of the members of the Society is very largely concerned with motorization and the application of machinery of which the internal-combustion engine is the heart, to the fundamental operations of production and distribution of the staple articles of commerce.

The automotive engineer is preparing for the greater and greater intensification of machine and traffic methods that will inevitably come in this Country, and for world-wide trade on which all our operations are so widely based. In this he is not forgetting sane requirements in the demand for the various types of automotive apparatus, or the vital necessity of the maintenance of standardization that will make possible that interchangeability of many materials, parts and accessories that is

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economically requisite. Many of the benefits of civilization are furthered by the activities of the Society.

At the dinner, George E. Roberts pointed out that if anyone knows what is the matter with the world at the present time, it is the engineer. With the division of labor in industrial development, the engineer devised ways and means to increase productive power as a whole. The loss of the world equilibrium, the equilibrium in world trade, has cost us a state of equilibrium in this country, notwithstanding the fact that owing to our resources being so varied and so great we are more nearly independent of the rest of the world than any other country. Mr. Roberts' theme was that there cannot be a state of general prosperity in either international trade or domestic affairs without an equilibrium in industry; that there cannot be a full distribution of products or full employment unless industry is in balance, all business in the last analysis being simply an exchange of products. The town industries and the great farming industry, together with the people immediately dependent upon it, must be brought into a comparative state of balance. All of the wage earners in an industry together do not have in their power the fixing of the amount of the wages that will be paid in the industry, because the amount of wages that will be paid depends upon the amount of goods that can be sold, and in turn the amount of goods that can be sold depends upon the ability of the public to buy. The engineer has shown the whole world how industry can be revolutionized by highly organized production. The engineers have done more than any other group of men to teach the lesson that the essential thing about wages is not the wage rate per week or per day but the cost of labor per unit of product. That is the golden key to the solution of the entire industrial problem. The people of this country must understand that they are vitally concerned in large-scale increasing production. There is no limit to the benefits that can be derived in this respect.

In connection with the expansion and restriction of credits, Mr. Roberts said that it is an established fact that people in general never use the earnings of good times to pay their debts but use them as a basis for further borrowing. People make their debts in good times and pay them under pressure in hard times. The condition of this country is remarkably good considering the experience through which we have passed and the readjustments that were absolutely necessary. In other

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similar situations in our history the reaction in business has come from a period of expansion during which there was a great amount of development and construction. We have had a period of expansion due to our expenditures in war, this being stimulated by war business. The country is much underbuilt today. There is a great backed-up demand for development and construction work which will be done speedily provided the general conditions in industry are favorable. There are millions of automobiles which ought to be built, and airplanes should be produced, as well as enormous amount of other automotive apparatus; and they will be built as soon as the industries of the country are brought back into balance.

Toastmaster Kettering expressed the view that the members had never attended a banquet at which they received more real substantial information, this dinner giving a new perspective of the whole business situation. He said that the engineers understand what the sales department wants: something they can sell; that last year the sales departments blamed the designing and producing engineers because automotive apparatus was not turned out fast enough, and say now that the trouble is that it is not good enough.

Aeronautical Engineering Session

The aeronautical engineering session, directed by Glenn L. Martin, aroused considerable interest and was attended by 210 members and guests. The paper on Airplane Propellers by F. W. Caldwell, read by L. E. Pierce in the absence of the author, outlined the progress made in propeller design and construction during the past year. Grover C. Loening read a paper on the Design Requirements of Commercial Aviation.

C. D. Hanscom in his paper on Airplane Wings, described some recent wind-tunnel tests of new wing sections and presented curves indicating the characteristics of these sections which showed that unusual efficiencies had been attained. Major Thurman H. Bane was unable to present his paper on the Progress of Military Aviation but was ably represented by Major H. S. Martin, who gave a very interesting description of the recent work done at McCook Field. Pictures were shown of experimental aviation engines of unusual types, the latest models of war planes and the new airplane cannon developed by the Ordnance Department. The motion pictures of parachute jumps were very entertaining and

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impressed the members with the practicability of the parachute as a life-saving device.

Annual Business Meeting

President J. G. Vincent was in the chair at the annual business meeting held during the morning of Jan. 12. After expressing his appreciation of the splendid support and cooperation accorded him during the past year by the officers and members of the Society, he gave a comprehensive survey of the Society's activities during this period.

In reference to membership, it was brought out that there was a net gain of 715 members for the year as compared with 651 for the previous year. The activities of the various Sections were considered as having been highly commendable and the belief was expressed that the Sections are experiencing healthy growth. The work of the administrative committees was pronounced most satisfactory as to both volume and quality, under conditions that had made this work more than usually burdensome.

Passing then to the work of the Standards Committee, President Vincent summarized its comprehensive activities, stating that in one sense the real value of standardization is just beginning to be realized, and suggested that doubtless much more can be done by way of simplifying, facilitating and improving the manufacture of the products with which the automotive industry is concerned and the economical use of which in service must be fostered. He then enumerated the many present cooperative activities of the Society with the work of other societies and organizations in allied fields, inclusive of active cooperation with various bureaus and departments of the Government, placing emphasis upon the solution of the fuel problem. It was suggested, however, that there is a limit dictated by common sense to the scope of coordinated activities that can be beneficial jointly or severally and that, with regard to both the domestic and foreign affairs of the Society, this should operate to protect it from too great complexity of effort. In this connection and also concerning the relation of the Society to the Federated American Engineering Societies, it was stated that a properly conservative policy indicates the assumption of a continuance of the Society's previous attitude of close attention to automotive matters in practically the same degree as heretofore.

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The efficiency of the organization and the work of the Council and the office staff of the Society were commended and comparisons in regard to the Society's remarkable growth were made, inclusive of financial and publication statistics. Since the time that Coker F. Clarkson became Secretary and General Manager of the Society 10 years ago, at which time the office equipment consisted of desk space in an office, there were less than 400 members and Mr. Clarkson was the sole employe, the office staff has increased to 50 persons, the office space required is 7500 sq. ft. and there are over 5000 members of the Society resident throughout the world.

President Vincent then discussed the future activities of the Society at considerable length and indicated desirable procedure along the lines of standardization, both national and international, foreign relations, the work of the proposed Research Committee recently authorized, committee and Sections' work in general and the work on internal-combustion engine fuel. The future problems of the automotive industry were enumerated and commented upon by him in considerable detail, these being inclusive of the successful quashing of the present general idea that the passenger automobile is to a large extent a luxury, the prevention of possible greatly increased taxes on automobiles and trucks, the need for a Federal licensing system because of the increasing amount of interstate commerce by motor truck and the removal of the three handicaps—road construction, fuel and cost—which must be accomplished before the automobile can render its full service to this country. The obstacles to the removal of these handicaps upon the industry were specified and an outline of much practical value for overcoming them was given.

The final portion of President Vincent's address was devoted to a summary of aircraft development and a discussion of its possibilities. It is evident that there has been a steady improvement in the reliability of the airplane, an extension in the use of aircraft where this was justified by the inherent advantages of this system of transportation and attainment in the field of research limited alone by the funds available. President Vincent stated further that perhaps the most conspicuous tendency in airplane engine design is to pay more attention to efficient operation at altitude and under reduced-throttle conditions obtaining during average flights. This involves in some cases special precautions against running

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wide-open near the ground, except for short periods with the aid of special fuels to guard against preignition and detonation. In this manner it is possible to effect considerable savings in fuel-consumption at altitude, together with an increase of available power under normal flying conditions.

Financial Report

The report of Treasurer C. B. Whittelsey for the fiscal year ended Sept. 30, 1920, showed the total assets of the Society to have been $151,627.39. The total liabilities were $21,977.31, making the unexpended balance in the treasury $129,650.08 at the end of this period. The income for the year, including initiation fees, dues, publication, advertising and miscellaneous sales, and contributions and interest, amounted to $247,206.55. The operating cost for the year was $227,650.43, which leaves $19,556.12 as the unexpended income for the last fiscal year and is a commendable result.

Report of the Council

The substance of the report of the Council is embodied in the Treasurer's Report, the report of the Membership Committee and the list of members elected during the past year. In addition, Mr. Clarkson touched briefly on a few other specific and general matters.

Regarding the present status and growth of the automotive industry, as indicating the volume and complexity of the future work of the Society, Mr. Clarkson went on to say that if one glances back to the time of William Shakespeare, the greatest of British poets, one will recall that in 1586 he made his way to London in search of work and opportunity. London at that time had 150,000 inhabitants. In those days there were two well established routes from Stratford-on-Avon to London. The roads were few, bad and dangerous. Journeys were made in the saddle or on foot; there were no other methods of travel. Goods of all kinds were carried by pack-horses; wagons were very crude and very rare. It should be borne in mind that vehicles were not run as public conveyances until the seventeenth century was well under way.

Today, at least 8,500,000 automobiles, passenger cars and motor trucks, are in greater or less use in the United States. There are, in addition, nearly 400,000 farm tractors; more than 1,000,000 stationary engines of the in-

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ternal-combustion type; and probably over 200,000 motorboats. These machines, approximately 10,000,000 in number, consume a large percentage of the 100,000,000 bbl., more or less, of gasoline produced annually, and a large amount of kerosene.

In 1923 there will be in use, allowing for machines discarded after five or six years of service, probably more than 9,000,000 passenger cars; close to 2,000,000 motor trucks; upward of 1,000,000 farm tractors; and more than 1,500,000 stationary engines. This means, without counting aircraft, over 13,000,000 machines of the various types mentioned, if the economic and financial balance hoped for is restored soon.

As we reach and advance from this stage we shall need another Shakespeare to visualize and guide our activities. In any event our work is cut out for us on a very large scale. The Council bespeaks accordingly the best effort and aid of all the members of the Society in conformity with its established precedents and in continuance of the remarkable loyalty and the generosity of the members that have made the achievements of the Society possible.

Report of the Standards Committee

The Standards Committee reported for approval at the meeting 34 recommendations; 13 were on new subjects, 17 involved revision and extension, 3 were cancellations of previously accepted recommendations and 1 was a special report. In January and June, 1920, there were reported 48 and 49 recommendations respectively, by 14 Divisions. The number of Standards and Recommended Practices contained in the new edition of Vol. 1 of the S. A. E. Handbook, recently issued in rearranged form, is 210. The Committee has now in hand in various stages of progress more than 200 subjects.

Election of Officers

T. S. Kemble, Glenn Muffly and C. E. Heywood were appointed as tellers of election of officers to serve during this administrative year and of Councilors to serve during 1921 and 1922.

They reported that 917 valid and 14 invalid ballots had been cast, 884 of the valid ballots having been according to the nomination and 36 miscellaneous. The total count on election is given on the opposite page.

Those receiving the largely preponderating numbers of votes were the nominees of the regular Nominating

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For President
(To serve for one year)

	For	Against
David Beecroft	910	7
H. W. Alden	1	
W. P. Chrysler	1	
H. L. Horning	1	

For First Vice-President
(To serve for one year)

H. L. Horning	911	6
A. W. Scarratt	1	
David Beecroft	1	

For Second Vice-President
Representing Motor Car Engineering
(To serve for one year)

B. B. Bachman	910	7
H. L. Elfes	1	
A. T. Sturt	1	

For Second Vice-President
Representing Aviation Engineering
(To serve for one year)

H. M. Crane	912	5

For Second Vice-President
Representing Tractor Engineering
(To serve for one year)

E. A. Johnston	904	13
D. P. Davies	1	
A. W. Scarratt	1	

For Second Vice-President
Representing Marine Engineering
(To serve for one year)

Joseph Van Blerck	910	7

For Second Vice-President
Representing Internal-Combustion Stationary Engineering
(To serve for one year)

T. C. Menges	911	6

For Councilors
(To serve for two years)

W. A. Brush	905	12
F. W. Davis	914	2
H. A. Coffin	1	
Allen Loomis	1	
Horace Smith	1	

For Treasurer
(To serve for one year)

C. B. Whittelsey	915	2

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Committee, no other nominations having been made. and were declared elected.

Sections and Meetings Committee Reports

Thirty meetings have been held during the past year by the 10 Sections of the Society, the subjects discussed having been related not only to engineering problems but to the economic trends of today. The Section established in Boston and the Section continued at Washington after the war period have been successful from the start.

The Meetings Committee report enumerated the important general meetings of the Society held during its 1920 administrative year and stated that there had been a total attendance at these meetings of approximately 2500 and an attendance at dinners held by the Society of about 2800.

During the summer and autumn of 1920 the Society participated in meetings of the National Gas Engine Association at Chicago, and of the American Petroleum Institute at Washington. During the year, 93 papers were presented, classified as follows: Aeronautics, 14; bodies, 6; fuel, 28; motorboat, 8; passenger car, 8; farm tractors, 6; transportation and highways, 10; motor trucks, 6; and general topics, 7.

Body Engineering Session

The Body Engineering Session on Wednesday afternoon could hardly have been excelled for display of enthusiasm and interest. All of the hundred or more in attendance expressed the greatest approval of the Society's recognition of this branch of automotive engineering. Papers contributed by Andrew F. Johnson and Kingston Forbes emphasized the importance of the art of automobile body design and urged future cooperation among the men engaged in the profession. The paper read by George J. Mercer outlined the predicted trend of passenger-car body design for the coming year. The various body types were treated by Mr. Mercer and desirable color schemes suggested.

Charles A. Heergeist, the venerable carriage and body engineer, was present, his paper on the possibility of reducing body weight being read by A. P. Cardwell. This paper aroused an unusual amount of valuable discussion. The use of veneer as a weight-reducing medium has not met with favorable results apparently and it is felt that there is still a considerable field for design study to secure lighter weight.

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The chassis and body engineer must cooperate to attain the proper result in this regard. It was the general expression of those present that the body must be heavy to withstand the strains resulting from chassis frames which are not stiff enough. George E. Goddard gave a very interesting description of the production methods employed in manufacturing all-steel bodies in large quantities, illustrating his talk with motion pictures.

Chassis Session

At the technical session on Wednesday afternoon covering chassis design for fuel economy the principal thought in the minds of practically all the speakers was that while high fuel economy had undoubtedly been obtained in Europe, these results were by no means disparaging to American motor cars since in nearly every case the cars tested were either light-weight stock cars of designs that could not be successfully utilized in America or were cars of a size comparable with present-day practice in this country that had been materially lightened by the removal of every piece of surplus equipment. H. M. Crane, who presided, stated in his opening remarks that the public is entitled to speedy, comfortable transportation regardless of the amount of gasoline consumed.

J. G. Vincent compared the demands of economy and performance. He said that gasoline economy is not the only economy in car operation and that the three factors that determine the economy of a car are chassis design, engine design and tires.

Two papers were presented at this session which were not closely related to the fuel economy phase of chassis design. One of these dealt with Torsional Strength of Multiple-Splined Shafts. In presenting the paper the author, C. W. Spicer, described a number of tests which had been conducted by his company. These showed that a splined shaft has a torsional elastic limit of approximately 18 per cent less than a full round shaft of a diameter equal to the small diameter of the splined shaft. This is directly opposed to the conclusion which would be obtained superficially that the torsional strength of the multiple-splined shaft is greater than that of a full round shaft. The other paper by S. E. Slocum which dealt with a Principle of Engine Suspension, described an application of the three-point principle of support for automotive apparatus, the main object being to relieve the chassis of the vibration transmitted to it by the engine, some of the effect of vibration on the chassis be-

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ing loss of power and fatigue of the metal employed. The vibrations Mr. Slocum stated are most noticeable with the closed type of body. While the three-point suspension of the engine was discussed at some length in the paper, the author stated that numerous other applications of the principle are feasible.

Commercial Aviation Session

Vice-President Glenn L. Martin, who was chairman of the Commercial Aviation Session, presented a most instructive paper on Commercial Aerial Transportation.

Prof. E. P. Warner's paper on Commercial Aviation in Europe was illuminative and afforded an opportunity for better comprehension of the remarkable progress and accomplishment made there in commercial lines. Reviewing the present European routes now in regular or partial operation, he stressed the essentialness of the attitude of the press in general being favorable if commercial aviation is to become wholly successful.

Aerial Transportation was comprehensively considered by Ralph H. Upson in presenting his paper on this subject. He gave an outline of the fundamentals and divided the subject into a discussion of what we have at present and what must be considered for the future, stating that it must be left to the inventors as to how far they can go in providing equipment.

The paper presented by S. W. Sparrow gave in succinct form the Relation Between the Compression Ratio and the Thermal Efficiency of an Airplane Engine.

Fuel Session

The intense interest of the members in this feature of the Annual Meeting of the Society, held Jan. 13, 1921, was manifest throughout its continuance by the large attendance at both the morning and afternoon sessions, by the close attention paid the speakers during the presentation of their excellent and comprehensive papers and by the spirited discussion which followed.

President Vincent was chairman at both sessions. At the opening of the morning session he made some very pertinent remarks relative to the fuel situation in general and to the necessity of active cooperation with the oil industry in the solving of the fuel problem. Following his remarks, he called upon Charles F. Kettering to present the subject of Fuel Research Developments.

Previous to calling upon Frank A. Howard to present his paper on the Volatility of Internal-Combustion En-

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gine Gasoline, President Vincent remarked that the fact that nothing went wrong in the performance of the single-cylinder Liberty engine, with which he is so intimately connected, indicates that a large portion of the difficulties experienced at present is caused by poor distribution of the fuel to the various cylinders in a multi-cylinder engine.

The next paper presented was that of C. A. Woodbury, H. A. Lewis and A. T. Canby, the subject being the Nature of Flame Propagation in a Closed Engine Cylinder. The possibilities with regard to suppressing knock in an internal-combustion engine cylinder were discussed. The photographic method was used to study flame propagation. Gas was exploded in a cylinder of constant volume which had no piston and the photographs were made through a glass window. A photographic diagram of the apparatus was shown and explained and a table giving the velocity of the flame-movement for various mixtures of acetylene and air was presented. Numerous photographs of the flame-movement of different fuels were then shown and commented upon.

The difficulty of producing detonation in a small combustion-chamber was mentioned and the statement was made that the tendency to detonate is not increased by an increase of temperature.

At the afternoon session, the first paper was presented by Reuben E. Fielder, entitled Air-Temperature Regulation Effects on Fuel Economy.

A. L. Nelson presented an unusually interesting and comprehensive paper on the Fuel Problem in Relation to Engineering Viewpoint. He stated that it is believed that never before in the history of the Society of Automotive Engineers has a single problem been so universally studied as the fuel problem that is confronting the industry today. It is also believed that never before has the industry had a problem which includes such a wide scope of work. The solution calls for the service of every class of engineer, inventor and scientist.

Dr. H. C. Dickinson gave a résumé of the fuel study made by the Bureau of Standards. In connection with the effect of compression on a dry mixture, curves were shown to illustrate that gasoline vapor compresses when "dry." Detonation was evident when using one spark-plug and there was no detonation when using two spark-plugs. After preliminary experiments of the nature already indicated, a pressure indicator was used, at pres-

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sures just on the verge of detonation, to find the exact point where detonation occurs. Slides were exhibited to show the position of the piston with reference to its center position, with one spark-plug and with two spark-plugs; and the effect of spark advance on maximum explosion-pressure and brake-horsepower, using one spark-plug.

Highway Session

At the Highway Session held Wednesday afternoon Past-President H. W. Alden presided. In his opening remarks on Automotive Obligations Toward Highway Development Colonel Alden emphasized the fact that the automotive industry is responsible for other things than the actual building and selling of motor cars and pointed out that the correct solution and proper arrangement of railroads, highways and waterways in the general function of merchandise transportation will have a wonderful effect on the future of the entire automotive industry.

The first paper of the session was by W. E. Williams on Highway Construction.

A. T. Goldbeck spoke on Government Highway Research. He specified the subgrade as the important factor in road building. There are three types of road failure; that produced by the horse-drawn vehicles which affect the surface only, the raveling action of the surface caused by rapidly moving automobiles, and the structural failure in which both the subgrade and the surface are affected. The various researches which the Government is conducting in the subgrade fundamentals and impact tests, and the way in which they are conducted were explained.

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ANNUAL DINNER

The Annual Meeting terminated on the evening of Jan. 13 with the highly successful Society dinner at the Hotel Astor, over 1100 members and guests being present. After appropriate remarks, President J. G. Vincent introduced Past-President C. F. Kettering as toastmaster for the evening. The other speakers were David Beecroft, then president-elect of the Society; R. E. M. Cowie, vice-president of the American Railway Express Co., whose subject was the Coordination of Transportation Media; and George E. Roberts, vice-president of the National City Bank, New York City, who spoke on the Crux of the Present Economic Situation.

PRESIDENT-ELECT BEECROFT

I wish to thank the fellow membership for the honor conferred upon me. It is a great privilege to have the opportunity of heading an organization of over 5000 men and to be president of an engineering society that is unique in that it represents a circle of industries. This circle is composed of eight distinct but closely related industries, all centered about the use of the internal-combustion engine. The automotive engineer probably requires the services of the editor more than other engineers because the piece of apparatus in which the internal-combustion engine is installed has gone into the hands of the average citizen of all the countries in the world and it is necessary, if we can get the information from the engineer, to carry the message to the users of this apparatus rationally as to how it should be used.

Editors think that this apparatus is yet far from being in a perfected state. We are glad to have the laymen agree with us in that. The motor car, which is not the oldest of this circle but is the largest, still has many problems ahead. We give all credit to those engineers of Europe who, in 1885, began bringing together the fundamentals, and we have wisely builded upon their early work. There is one great credit that goes to the Society of Automotive Engineers; namely, that it had the good judgment to take and translate into the requirements of this country those fundamentals that were so well worked out in Europe. It was very fortunate that our manufacturing centers were located in the region of

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the Great Lakes, bordering on one of the greatest agricultural areas in the world, an area that has already given evidence of being one of the great consuming areas of automotive apparatus. What is happening in this agricultural area is happening in all similar areas in the world. We could scarcely do anything else but develop automotive apparatus and translate it into what we now have. It was the voice of those thousands of square miles of country calling for apparatus, the voices of those 7,000,000 farmers demanding improved transportation and the voice of great areas with sparse population, requiring some speeded-up method of transportation in order that the homogeneous character of this country should be maintained and that the urban population should not lead the rural too far, that induced automotive development. What has been a greater factor in bringing the rural population up to the level of the urban population than the internal-combustion engine in its various forms?

We developed this apparatus and the great production plans that have carried internal-combustion-engined apparatus to the four quarters of this country. In the earlier years of the war we found the nations of the world knocking at our doors for this apparatus and we immediately gave heed. Soon, this apparatus, so well fitted for our areas of poor roads, great distances and sparse population, found itself excellently fitted for use by the nations of the world. We unconsciously came by a great heritage in that we builded in the zone of requirements where conditions were crude, whereas Europe had been building under conditions that called for a different type of vehicle. We have this great field ahead. We have found our factory capacity greatly expanded because of the war. We must give attention to the remainder of the world. The motor vehicle is an international piece of mechanism in all its forms and our engineers must look beyond the confines of their own country. I can think of nothing that would be more useful today than that these engineers go into other countries and see the conditions under which their apparatus must operate, see face to face the peoples who are destined to handle it, and then have due regard for those conditions in the improvement of the apparatus.

What must be the ultimate object of the engineer in all this apparatus? In its design he must recognize the work, the people and the environment, always keeping in mind that he is best serving this country and all the

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countries of the world to which our apparatus must go, when he designs and makes the apparatus so that it is easiest to purchase, easiest to apply to the job, easiest to operate and easiest to maintain.

R. E. M. COWIE

It was aptly said by the toastmaster, in speaking of the different means of express transportation, that everything from a wheelbarrow to an airplane is included in our service. The express business began some 75 years ago. It was not dignified at the start even by a wheelbarrow, because the single individual who originated the industry relied upon a gripsack. Within a very short time his business increased enormously and he had to invest in this wheelbarrow, but even that proved too small for his needs and led him to obtain certain space in a stagecoach. From that the business turned to other modes of transportation, the boat on the inland waterway, the steam railroad and steamboats, and has developed now to include every known means of conveyance. Until a few years ago, the express traffic in the cities was carried almost entirely by horses and wagons, in these days regarded as a slow and tedious means of transport. The American Railway Express Co. employs today upon the Island of Manhattan 650 motor and 550 horse-drawn vehicles.

There is a very distinct place for the motor vehicle, whether propelled by electricity or by gasoline. There is just as distinct a place for the horse-drawn vehicle. It is unfortunate that horse-drawn and motor vehicles must operate in the same string of traffic. I do not know how that can be remedied in the densely populated cities, but the problem must be solved.

Simplification of Product

The motor vehicle is a wonderful machine, but it is too complicated. It takes a high degree of intelligence and engineering skill to design a vehicle of so many different parts, coordinate those parts into one apparatus and make it function successfully. Still greater ability is requisite to eliminate a number of those parts. The cost of upkeep of the ordinary motor vehicle makes the average man stagger. This is due in part to the present high cost of labor and material, but if there is any way to simplify the internal-combustion-engined vehicle, I advise that this be done. Forget about what competitors do. It seems to me sometimes that the sales department

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of the average automobile manufacturing company merely wants the engineering department to put on fancy appurtenances so that it can have some little points to talk about that competitors do not possess. Wipe all these off; eliminate from the chassis everything but the absolutely essential parts. The efficiency of the vehicle will thereby be increased, its cost of operation reduced, and a greater field for its sale opened. The motor vehicle may appear to a scientific man to be a very much simplified machine, but we cannot get scientific men to operate our motor vehicles. The simpler the machines are, the more efficient they are, the less liable to trouble and the more economical in operation and upkeep. I cannot imagine any line of study that can be more profitably followed by automotive engineers than the simplification of the product in which they are interested.

The value of the motor vehicle as a means of transportation cannot be overestimated. The things that it has accomplished are marvelous. When the United States decided to enter the recent war, money and motor vehicles were preeminently needed and these two things were immediately found and furnished in this country. The engine that automotive engineers designed and the motor vehicle that they constructed won the battle of the Marne, prevented the fall of Paris and changed the whole complexion of the war. It was possible for the United States Government to furnish, for itself and for the Allies, vehicles to motorize the artillery, the ambulance service, the food service, supply and ammunition trains and everything that must follow up or precede an army, because the automobile industry was upon a sound, going basis and foundation.

Fostering of Commercial Aviation

The United States Government should adopt a far-sighted, consistent and constructive policy with respect to commercial aviation. It is true that the Government has, through meager appropriations by Congress, been able to conduct certain mail routes which, considering all the circumstances, must be admitted to be signally successful. I can conceive of no good reason why the Government should not encourage and support commercial aviation in the same manner that it has encouraged and supported navigation on the seas. In the one instance the Government furnishes maps, charts, lighthouses, whistling buoys, life-saving apparatus and the like. Why should it not furnish landing-fields, illuminated airdromes, wire-

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less directional apparatus, licenses, proper legislation and all the things calculated to make commercial aviation successful? From an experience of many years in the transportation business, I believe that the people of this country would avail themselves very quickly of service by air, just as they availed themselves quickly of service by parcel post. The parcel post attracted and built up a business peculiar to itself. I predict that the airplane service, where it covers a sufficient distance to eliminate a certain amount of time, will be taken advantage of immediately by the commercial interests of this country. Commerce persistently demands the most approved and expeditious means of transportation. I hope that soon the United States Government, through its mail department, and the American Railway Express Co. will join traffic and use the same machines to encourage commercial aviation. These must be specially built machines for carrying the Government mails and the extra emergency shipments offered by the public for express transportation.

In my judgment, the possibilities of commercial aviation offer the members of the Society of Automotive Engineers as great a field of endeavor as any field they have entered.

C. F. KETTERING

We have not really awakened yet to a realization of what aviation is. If we talked about everything the way we do about aviation, we would still be riding around in ox-carts. I have said time and time again that we have a lot of people riding in automobiles who have ox-cart minds. The great trouble with aviation is that we do not appreciate what a tremendous thing it is. We do not appreciate the meaning of an increase in the speed of transportation of from three to five times what we have ever had before. The idea is too great for people to grasp. We certainly wish to thank Mr. Cowie for his stimulating message to this audience in favor of aviation. When an unbiased, unprejudiced individual talks that way, those are wise who pay some attention to what he says.

Most people when they go up in an airplane for the first time and the pilot gives them a "stunt" flight, come down and say that they would not accept $1,000,000 to do it again; on the other hand, if the pilot gives them the right sort of a flight, they come down and say that

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it was the most wonderful experience they ever had. Everyone ought to take a ride in an airplane. If an airplane passenger has any personal conceit, such an experience will remove it before he again reaches the ground. If one is general manager of some great factory, reaches an altitude of 5000 ft., looks back and sees a little bit of a factory about the size of a postage stamp, one is bound to realize that he is not so much, after all. Nothing else in the world will give one such a perspective of the relationship of individual activities to world activities as a flight in an airplane. I said, the first time I went up, that it looked to me very foolish to quarrel about 2 ft. on a line fence, one side or the other, and I still think that.

We have had two men speak about the necessity of studying automotive apparatus from the user's standpoint, and I think we all realize that this is a fundamental problem. Of course they are blaming all the faults on the engineers. No class of people realizes the faults of automotive apparatus any more than the engineers do, because engineers look over the trouble reports and others do not. Our whole economic situation has changed. We must build an entirely different type of apparatus in the future than we have in the past. We must recognize that the customer who pays for these automobiles has a right to ask for something, and that unless we design from the standpoint of the customer, we will get into trouble. If President-Elect Beecroft will focus his attention on that particular idea and print it and talk about it to the commercial side of the industry so that it will not overrule the engineers, that will help very much.

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ANNUAL MEETING PAPERS

THE ENGINEER'S PLACE IN THE INDUSTRY

Following the regular business session at the Annual Meeting, Jan. 12, 1921, the subject of the Engineer's Place in the Automotive Industry was presented in addresses delivered by H. M. Crane, H. W. Alden, F. E. Moskovics, J. G. Utz and J. G. Vincent. The remarks of the different speakers are printed below substantially as delivered.

HENRY M. CRANE

When I began thinking about the origin of engineering as a profession, I was much surprised to realize that it is of extremely recent growth. In making this statement, I draw the line possibly in an arbitrary manner between the experimenter, the investigator in chemistry or physics or allied lines, and the men who take the results of such research work and put them in form for the use of all the people. I think that this is a very reasonable line to draw. A misunderstanding has existed among many of the executives in the automotive industry, especially its financial men, as to the radical difference between scientific experiment and engineering practice, which are of equal importance. This has caused much friction and possibly retarded the progress of the engineer toward a place in the industry equal to that occupied by the selling and production departments.

If we look back only 100 years, we see the shipyard workers fabricating ships designed by the builders; the men who actually produced the ships decided what they would be, in both form and structure. Not 15 years ago, in the coach-building end of our own industry, there were many coach-shops in which the drawings were nothing but the simplest kind of sketches. These were used only as a general outline for the workmen, who took the material and formed it into the desired shapes themselves, guided by their long experience. I believe that such a form of manufacture has many good points; the close connection between the design and the manufacture produced very practical articles. The two departments

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practically were one. The articles possibly might be criticized because of theoretical considerations, but the men who were successful became successful because what they produced actually operated and gave service.

The Era of Specialization

As industry and the individual industries became greater in size, we started on an era of specialization. I imagine that the beginning of the engineering profession was largely in the drafting-room, where the then engineers put down the ideas of the boss as a matter of record, for future reference or to be transmitted to the workmen. The activities of these engineers, who were then engineers in name only, if at all, continually broadened as time went on until in many cases the designing came entirely under their direction. However, in the automotive industry this designing was largely the primary stage of production, because no design was sacred from the hands of the production man. I do not take the attitude that designs should have been sacred from the hands of the production man; I simply am making a statement which we all recognize to be true.

Those who have followed me so far will feel, with me, that the engineer has reached a milestone in his progress, but that he has still a considerable distance to go. The engineer and the shop and the sales department in many of our companies are too widely separated at present; in other words, we have reached the extreme of specialization. In the mind of some men the engineer is not supposed to know about what a salable automobile should be, but should take his directions from the sales department; he is not supposed to know how an automobile can be built in an economical manner, but should take his information from the shop. The shop, likewise, is not supposed to know what constitutes a correctly designed automobile, but is supposed to take its information from the engineers. It is evident to me that a system rigidly conducted on those lines has very little chance in competition with the old system of 100 years ago in which the knowledge was combined in one executive, in the final efficient production of the best article. I do not wish to be understood as saying that we can go back to the conditions of 100 years ago; we cannot. No man living is big enough, mentally, working the hours per day that a human being can work, to combine in himself all of the various forms of knowledge required in the oper-

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ation of a large plant such as the financial requirements, the human element of handling the workmen and the tremendous factors of that kind which did not exist 100 years ago. On the other hand, I think we can approach the efficiency of the old system if the engineers will grow to the point to which I am sure they can grow, and that they will attain in the not very distant future.

The engineer is expected today to know in general the foundation principles of the vehicle he is designing, the use to which it is to be put, the action of the various parts and the probable strains to be met therein, the general theory of combustion in internal-combustion engines and like matters. I do not see why the man who is mentally capable of understanding and applying those principles is not mentally capable of understanding and applying what to me are the much simpler principles of machine production. The fully equipped engineer should be thoroughly conversant with the principles of cutting metal of all kinds in all forms. These principles are really simple and actually very few in number. In addition, the well-grounded engineer should know the capacity for accuracy of the various production operations. For instance, he should know what a grinding machine that grinds shafts of 1-in. diameter should be able to do, day after day, in thousandths of an inch of tolerance either way from the desired size. He should know the same things regarding the grinding of cast-iron cylinders, the machining of aluminum parts and the cutting of gears. Not only should he know these things but, in preparing his designs, he should use such knowledge at the start.

Some engineers feel that the shop will take care of these things and that the whole burden on them is to have something that will run. That is the fault of specialization. Unless the engineer has the fullest comprehension of the difficulties to be met in the shop and gives as much attention to those questions as he does to the questions of the best form of combustion-chamber and the kind of spark-plugs to be used, we cannot get the efficient operation of our factories that we ought to have. The shop, under those conditions, has to meet the engineer half-way. I have had experience with seven factory managers in the last five years. The difference between the best and the worst of those factory managers was almost entirely in their point of view. The best one took the viewpoint that he was building an operating engine. He encouraged his foremen and his superintendents to look at it in the same way. The reverse of this condition is

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when the foremen and the superintendents look at the product solely as so many piece numbers for which they have blueprints and what is to them an entirely arbitrary inspection. My contention is that the shop which educates its personnel to realize that the inspection is not arbitrary, that it is based on certain definite requirements, will go a long way toward obtaining the highest class of results in the cheapest possible manner.

Salability of the Product

I think another branch of the automotive industry comes equally within the province of the engineer; it is the salability of the product. It is much more conceivable to me that the trained engineer is the best judge of what car should be built to meet a given public demand than that the sales department should be the best judge. The engineer knows what can be done and, if he is broad-minded enough and sufficiently observant, he ought to have a very thorough knowledge of why the public demand certain things in cars. I think it is not difficult to obtain such information without actually being an employe in a salesroom or a sales manager. In fact, I think the salesroom frequently produces a rather artificial point of view; it is the point of view of that day. The engineer's job is not to say what is salable today, but what will be salable two years hence when he shall have been able to design the piece of apparatus and the factory shall have had time to build it. That is why I say that the engineer, if his training is proper and if his point of view is correct, ought in general to be a better judge than the sales department of the proper thing to build to meet a given demand.

I am asking a great deal of the engineer. In fact, in many ways he must have a greater fund of correct information at his disposal than any other member of a company. He must know his own part of the work, the results of research in the past and of the research going on from day to day. In connection with production he must know the actual methods in many allied industries; he must know the general methods of drop-forging, the general methods of producing stamped sheet-metal work, and foundry and pattern-making methods. The automobile chassis plus the body includes in its structure almost every form of manufacture that we have today, and the engineer must have a thorough grounding in almost every one of those lines if he is going to do his part of the work successfully. I have outlined already the neces-

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sity for his knowledge of shop practice. He must have also a knowledge of merchandising which will lead him to have a correct judgment on what the public will want in the future, and a correct judgment that the article can be produced at the price that the public will be willing to pay for it.

I admit that today we do not live up to my ideals of an engineer, but I believe that, if the engineer will grow along the lines I have indicated, he will demand a much larger place in the industry than he fills today, because he will merit it.

H. W. ALDEN

There has been no time when the position of the engineer in the trade and particularly in the automotive industry has been any more at the parting of the ways than it is today. We have gone through a wonderful period of engineering development and experimental work; we have experienced an amazing time of commercial development, when almost anything that would run on four wheels would sell; and now, for the next few years and perhaps perpetually, we are faced with the situation of the survival of the fittest.

Engineer's Place Depends on Himself

In trying to outline what will be the position of the engineer in our industry, one of the things that occurred to me is that his position will be just exactly what the engineer makes it. In my work I come into contact with probably 150 different engine manufacturing companies more or less intimately; also with a good many purveyors of material. In some cases there are peculiar conditions to which what I say does not apply because of very unusual circumstances, but I have found it largely true that the standing of the engineering department in any commercial organization is measured very largely by the ability of the engineering department itself. As a concrete instance, if a motor-car company has a wide-awake, live engineering organization, that organization plays a very large part in all the activities of the company. If it is made up of individuals who are not any too strong, then that department does not cut very much figure and takes its instructions from other departments. Just what position the engineer will maintain in the automotive field or in any other field will be measured entirely by his service. Just so far as the engineer serves all branches of his

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organization and the industry with which he is connected, will he play a part.

We have engineers who have come from two sources. One is the so-called technical graduate; the other is the engineer who has come up through the ranks. I do not presume to make any class distinction between the two. Both those who have had a preliminary technical training in some engineering college as well as those who have carved their own way out and availed themselves of that line of study and development which they have gotten by their own hard work, have gathered together certain information, certain lines of thought and lines of action which it seems to me places a responsibility on them which does not rest on the shoulders of any other department in modern organizations.

Mr. Crane has spoken very forcefully of the necessity that the engineer know all sides of his business. I cannot let the occasion go by without emphasizing that. It is just as much the engineer's job, in my opinion, to know how a piece can be produced, as it is to design that particular piece; in fact, I cannot conceive how he can design a piece of apparatus intelligently unless he does know all the steps of production in that device. He may get something that will work, but he will not get the last word in that device. It is just as much the engineer's business to know where and how that article will be sold, as it is how it will be designed or made; but it is a very striking fact, as one talks with engineers and sees what they are doing, to notice how few engineers really seem to know what will be done with the product after they get it off their shoulders. My sympathy very frequently goes out to the shop man who has to make what the engineer designs, and to the sales department that must sell what the engineer designs.

So far as the individual in an organization is concerned, his value to that organization depends very largely upon the measure of responsibility which he is willing to accept. That is equally true of the engineering and the other departments in any company. All of us know men, perhaps men connected with our own organizations, who think that their little responsibility starts at a certain point and stops at some other certain point. If they are given a job that starts somewhat earlier and goes somewhat farther, they will shy at it. That kind of an engineer will never get very far and, unless that spirit is eliminated from that individual, he will fade away some day and will wonder why.

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Another characteristic of engineers, which is disappointing in many instances, is lack of thoroughness. It frequently is necessary to gather some information from which to draw a conclusion; to build up some device, we will say, to take the place of the device that is being investigated. I venture to assert that there are not five men in a hundred who can go out and make an investigation of the situation and come back with the solution. The man who cannot come back with the solution is not particularly valuable.

Briefly, I believe that the position of the engineer in the automotive industry today is at the turning point, and that he can make it just exactly what he wants to make it. The engineer ought to be the central figure in our organization but, unless the engineering organization in any business serves all branches of the business and merges its own individuality, ignoring questions of who is responsible for this or who is to get the credit for that, we will not progress as we ought to progress. I doubt if there is an engineering society in the world that has such an opportunity to serve its industry as the Society of Automotive Engineers has; but only insofar as we are of service will we succeed in attaining our proper position in that industry and in maintaining it.

F. E. MOSKOVICS

The individual that Mr. Crane described is not an engineer; he is an industrial wonder. When he attains such a position, he becomes the president of his firm. Mr. Crane left out only the financial side. Why he left out that detail I do not know. If the engineer is to be a judge of the commercial side of the demand without consultation with the sales department and can design the methods of production without consultation with the tool-designing and the production departments, why should he not know the small details of finance?

There are two forms of engineering that are not clearly recognized in their exact sense. I refer to those two forms constantly in our own business. There are some contacts that I believe no human being can get. A question just asked me proves this to my mind: "About what proportion of closed bodies are we going to build?" I said that limitations are put on one man, if nothing more than the limitations of geography; as long as San Francisco and Los Angeles persist in being 2000 to 3000

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miles from our source of production, I do not see how an engineer can be out there every two or three months.

Two Forms of Engineering

The two forms of engineering that I believe are developing more and more as the keynote of our industry are the following. First, technical engineering, which can be taught in any first-class school. The man who studies the other form I would call an empirical engineer. I do not know but that the empirical is a somewhat more important form than the other. The empirical engineer is the very type that Mr. Crane described. I have found that the very finest machine in the world, founded on the very best technical information, can be designed and that one or several can be built, driven to San Francisco or any other place on a test trial, brought back and put into production; and afterward when a thousand or more are put out there is something wrong. It is that something that I do not believe any one man can eliminate from an automobile without the cooperation of a number of other departments. The secret, to my mind, lies in those operations that can be turned into cooperations. That will bring us to the desired result. I think the czar that Mr. Crane described cannot do it without a most hearty cooperation of all the other branches, and unless he accomplishes it in the form of cooperations. If he is a czar, he might just as well have the name of it and be the president of the organization first as last. I will concede that interpreting the trend of future design is the greatest function of an engineer, but I believe that the engineer must temper his effort and be controlled by intelligent discussion and cooperation. A man cannot sit down and dictate some certain thing the public ought to have without having the ability to interpret that thing intelligently. To interpret it, he must have contact with the public. So long as the public persists in living in various places in different parts of the world, the man who interprets must listen to the salesman and the advertiser.

As to the cooperation of an engineering department with a production department, I cannot see it in any other way than that of actual contact between the two departments. I have for years past heard it said, not only in the last several years but in all the years that I have been connected with the automotive industry, "The design is absolutely right if only the production department would make it according to the drawings." The

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answer is that they would be right if only the production department could make the drawings commercial. If we can find an engineer that is a tool-maker, a designer, a shop superintendent and a sales executive, I will admit that he ought to be everything that Mr. Crane recommends, but then he could not be called an engineer.

J. G. UTZ

In listening to the remarks of Mr. Moskovics and to the various statements that have been made about cooperation, I am reminded of a remark I heard made some time ago. It is that the difference between failure and success is the difference between dignified acquiescence and cheerful cooperation. I think that engineers are getting more toward the latter field as we go along. The greatest development of the American engineering profession, particularly in the automotive line, has been brought about largely by the Society of Automotive Engineers. Some of us who were in the old mechanical branch of the Association of Licensed Automobile Manufacturers remember, in fact, so many years ago that only a few gray-haired men here and there can remember, that there was a time when the experimental department, the engineering department and most parts of the shop were under lock and key and had guardians at their doors. Going back into the ancient history of that time, I can remember a meeting of the A. L. A. M. at 7 East 42nd Street. Something was asked about the fit of piston-rings. Almost everyone told what he was doing but, in going around the room, they finally called on one member who said he believed he would keep his information to himself and that he did not want others to build as good a car as he himself was building. That attitude was prominent in those days, but it has gradually disappeared. Today, when traveling around as I have the good fortune to do now and then, about the first thing an engineer desires is to take a visitor down to his experimental room and show him what he is working on. The visitor sees things which will not become public for several years. The former practice of the profession was rather to keep such things to oneself. The very openness of the methods of engineers today, in regard to showing what they have, is one of the best criterions of the advancement of the American engineer. This practice is growing all the time.

I do not believe the statement that the Society of Auto-

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motive Engineers is standardizing the engineer out of a job is entirely true, although one can nearly design a car from the S.A.E. HANDBOOK today. Growth and advancement are evidenced by the fact that engineers are being moved up to positions of greater authority. We have some examples of engineers having arrived at the vice-presidencies and presidencies of their companies.

J. G. VINCENT

Mr. Crane and Mr. Alden have given a very good picture of why the engineer must in self-defense be thoroughly proficient. I think that one need go no further than just to realize that there is nothing in connection with the automotive industry that cannot be blamed on the engineer, thus proving that the engineer must be prepared to protect himself at every turn against every other department if he is to make a success. I know of no other department, in manufacturing or in the selling organization, that cannot be checked up with proof as to whether it is efficient. There is no really good way to check up whether an engineering department is efficient until all the processes have been gone over and the business made a success. Anything along the entire line can slip unless the engineer is there to protect himself.

ENGINEER SHOULD COOPERATE

Mr. Moskovics took a different view point from what Mr. Crane and Mr. Alden had in mind. I know that neither of the latter had in mind that this engineer should be a czar or that he should be anything except the finest cooperator in the world. What they did have in mind, however, is that he must know his business, so that the result of this cooperation will be along the right line.

I have had some personal experience in that connection. In one plant where I took charge of the engineering there had not been the proper cooperation between the factory and the engineering department. The engineering department said that the factory did not want to work to drawings, was not interested in building the kind of a vehicle that ought to be built, and that it could not get the factory to work to drawings. On the other hand, the factory said that the engineering department did not know anything about designing and drawings.

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There you are! We cannot expect cooperation until both parties have a fair idea of the other's job. If the head of the engineering department and his assistants know shop practice and have the right mental attitude, they will not have much difficulty in getting full cooperation from the shop. Most shops, if they are managed properly, really appreciate cooperation.

So far as the sales department is concerned, the engineer will have no trouble there either. He cannot, of course, have full details of information as to all that is going on throughout the entire country. The members of most engineering departments whom I know of are too busy to take extended trips very often, but if the engineer is the right kind of a cooperator and has the proper initiative he will be so closely in touch with the sales department that he will know more about those conditions than they themselves will know. This is because he will know the engineering reasons that underlie the results that the sales department is obtaining, or the results it is not obtaining. I think there is no doubt that the engineer is taking more and more responsibility for the various activities throughout the various plants. As Mr. Moskovics says, he is working then toward becoming an executive. Well, why not? I know many big executives in this country who have worked up from having been engineers. I can think of nothing better than a good engineering training and experience to fit a man for executive work.

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AUTOMOBILE OBLIGATIONS TOWARD HIGHWAY DEVELOPMENT

By H W Alden[1]

The author brings to attention very emphatically the responsibility of the automotive industry for some things besides the actual building and selling of motor cars.

The progress of civilization can be measured very largely by advances in means of communication. The transfer of messages by wire and wireless has made wonderful advances of a fundamental nature in recent years, but the transportation of commodities from place to place has not made such strides. The automotive industry has been concerned mostly with the actual development and production of the motor car and, as an industry, has stopped there without developing those allied activities which are vital to the long-time success of the business. The railroads afford a good example to follow in principle. Their roadbeds and the equipment operating thereon have been improved and developed hand-in-hand by the same general guiding influences and their wonderful advance in both is due fundamentally to this unified control of these two elements. A different condition exists today regarding highway transport. We have far better highways than formerly, but the author believes that the ratio between the demand on the highways and their ability to meet that demand has gone down rather than remained constant.

After expressing his sympathy with the difficulties confronting the highway engineer, the author rehearses the factors governing merchandise transportation and outlines means of betterment that should be promulgated by automotive engineers, with special reference to the construction and maintenance of highways for motor-vehicle use.

In opening this Highway Session, I wish to bring to your attention very clearly and emphatically the responsibility of the automotive industry for some things besides the actual building and selling of motor cars. We all know that the progress of civilization can be measured very largely by advances in means of communication. The transfer of thoughts and messages by wire and wireless has made wonderful advances of a funda-

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[1]M. S. A. E.—Vice-president, Timken-Detroit Axle Co., Detroit.

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mental and revolutionary nature in recent years. On the whole, the transportation of things from place to place has not made such strides. This is fundamentally due, I believe, to the fact that practical performance can be developed in laboratory investigations better in the former case than in the latter.

In electrical matters, such as the telephone and telegraph both with and without wires, the companies controlling the work have exhibited great foresight and shown great energy in all its phases. Perhaps it has been necessary to their very life that they should do so, but it is a fact that they have done so. This is far from true in the automotive industry. We have been concerned mostly with the actual development and production of the motor car and, as an industry, have stopped there without developing those allied activities which are vital to the long-time success of the business. Our railroads are a good example to follow in principle. The roadbed and the equipment operating on that roadbed have been improved and developed hand-in-hand by the same general guiding influences. The wonderful advance in both in the last 20 years is due fundamentally to this unified control of these two elements.

In the matter of highway transport, we find a different condition. It is true that today we have far better highways than formerly, but I believe the ratio between the demand on the highways and their ability to meet that demand has, on the whole, gone down rather than remained constant. The increase in numbers and capacity of motor cars has been greater than the extension and improvement of highways. It is my opinion that the responsibility for this rests squarely on the shoulders of the automotive industry itself. It is easy to criticise the highway engineer, but I venture to assert that the average highway engineer can come nearer qualifying as an automotive engineer than his automotive brother can as a highway engineer. If I should ask those present to stand up who have given serious thought to highway design and construction, not many chairs would be vacated. We cannot continue increasing the number and capacity of motor cars for our own profit and shirk the responsibility of helping in highway development. That is one of the facts I want to emphasize as forcefully as I know how. The long-time success of our business is inextricably interwoven with highway development. Unless this situation is more clearly understood and its les-

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sons learned by the industry, then the industry will not advance as it might.

My sympathy lies very largely with the highway engineer. Our engineering schools have, on the whole, been asleep and have failed to provide instruction in this work. Consequently, the highway engineer has had to blaze his own trail until very recently. Considering his handicap of political jobbery, it has been an uphill task. Until very recently, I repeat that the automotive industry has been occupied too much with making money and not enough with those allied activities which, for its own good, should have had its hearty cooperation all the time.

Merchandise transportation depends not only on cars and roadbeds, automobiles and highways, boats and waterways and, I might add for the future, airplanes and blue sky, but on the manner of use of these agencies. Here again we can learn a lesson from railroad experience. In the past the development of freight terminals and rail transportation has been under the same general guidance and the development of the two has been consistent and logical. The recent projection of the automobile into the transportation field has made possible wonderful changes in the methods of distribution of all commodities, but here again the automotive industry, as a whole, has neglected its full responsibility. It has failed to shoulder this responsibility for the correct use of the new instrument which it has produced, and for the proper correlation of it with previously existing instruments. I believe we are emerging gradually from our fools' paradise of money-making into a realization of this larger responsibility. How the railroads, highways and waterways can be best joined together in the general function of merchandise transportation is worthy of any man's time and intensive study. The correct solution and the proper arrangement of these three agencies will have a wonderful effect on the future of our industry.

Freight cars average little better than 25 miles per day, due to terminal delays which could be eliminated largely if the motor trucks and railroads were in proper relation. This daily average could be lifted easily to 75 or 100 miles if the inefficiency of present terminal methods were eliminated. This is no idle dream. The basic trouble is that railroads are doing an enormous amount of less-than-carload, short-haul work for which they are not so well equipped as is the motor truck. The average distance that each ton of freight is hauled by rail is

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less than 200 miles, due to this large amount of short-haul tonnage. A proper rearrangement wherein the motor truck would do the short-haul and the less-than-carload work and the railroads the long-haul work would give us a regular freight transportation more speedy than today's average express shipments and at a cost far less than anything dreamed of today. However, I have seen little indication of study of this problem by the automotive industry as a whole, or of cooperation with the railroads in its solution, until very recently. We cannot pass the blame on to the railroads. The responsibility is our own. It is a challenge to the brains of the automotive industry and, unless we get busy and assist in the solution of this problem, the progress of the truck industry will be slow where it might be rapid. The details of these questions are numerous, but they are not difficult of solution. They must, however, be honestly faced and understood. Then, if honestly attacked, the results will revolutionize our transportation business.

I am fairly well acquainted with what our industry has done in the fields of highway development and merchandise transportation, but I repeat that what has been done is only a drop in the bucket. I am greatly pleased that our Society is showing signs of life in these two directions, as they are at the very foundation of our future success and expansion. It behooves every automotive engineer to devote a goodly share of his time to studying these two questions. I hope what I have said will direct our attention more and more to these fundamental problems, the solution of which is as much our responsibility as it is that of the railroad and highway engineers.

THE DISCUSSION

CHAIRMAN H. W. ALDEN:—I doubt if there has been a time in the history of the automotive industry when it was as necessary as now for it to get out of its so-called legitimate line of work and pay attention to some other things. The matter of how highways shall be built must be left largely to the highway engineer who has been trained for that work, but that does not relieve the automotive industry of its responsibility to turn to and help. While I have been rather severe in my criticism of what the automotive industry has done in the past, I think it is well borne out by the facts and that we have not done our share by any manner of means. The same

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thing is true about the handling of merchandise. We build trucks and sell them to dealers to operate with no particular attention given to their correct and logical use, except in a very few cases, as at Cincinnati and Cleveland, particularly in connection with other transportation facilities.

W. E. WILLIAMS:—The term "hammer-blow," in place of "impact," will be better understood by the layman as a road-destroying factor. "Hammer-blow" was the term in common use with railroad track men years ago. As it relates to brick pavements, the hammer-blow of the iron-tired vehicles and the shoes of horses soon breaks off the corners of the bricks of the best laid brick pavement, until it becomes a continuous series of offsets producing vibration on the vehicle wheel treads that injures both the road and the vehicle. That the drainage should be good is so axiomatic that I need not dwell upon it. If it were possible to have a dry subbase, a thin hard surface would be sufficient.

CHAIRMAN ALDEN:—Mr. Williams has, to my mind, put his finger on the solution of the highway difficulty, but I do not agree with him that it is in limiting, within so-called reasonable ranges, the weights of vehicles. I question very much whether the present-day trucks are heavier than the well sub-soiled road is perfectly capable of standing. The Federal Highway Council has done much work along this line and has started to accomplish some very remarkable results in the coordination of various organizations working toward the end of improving the subgrade. They are finding out some very remarkable things. As Mr. Williams says, moisture in the subgrade is the enemy of the road. It is beginning to be apparent, however, that it is perfectly possible with proper knowledge and precaution of the soil in which the road is to be placed, to get vastly increased supporting power of the subgrade from what had been current practice today. In nearly every case where a failure occurs, the bearing power of the subgrade has been criminally low, much lower than necessary under the conditions confronted. This is not meant as a criticism of the highway engineer, because he also has had other problems to meet.

S. W. WILLIAMS:—A number of nationally known organizations, such as the American Automobile Association, the National Automobile Chamber of Commerce, and the Federal Highway Council, are earnestly and consci-

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entiously trying to solve the difficulties obstructing highway development. It is somewhat of an undertaking and is discouraging, but we are encouraged when an organization such as the Society of Automotive Engineers cooperates with us.

I have listened with greatest interest to the papers presented and discussed here today and I am much impressed. I am in entire sympathy with Mr. Williams in that we need roads, that we need more roads and that we need them just as fast as it is possible to build them, but I doubt very much if we want to begin to fit this new type of transportation to the road or highway rather than the highway to the transportation. A prominent highway engineer said in my presence recently that no highway engineer in the United States today knows how to develop a highway that will serve the transportation needs of the country 5 to 10 years hence. I believe that an analogous condition prevails in this Society. I doubt very much if automotive engineers have made up their minds that they know the type of vehicle that will serve the needs of this country. We fail to realize that the highways of this country have an earning capacity, and that earning capacity will be increased with the economic service rendered. Therefore, the real controlling factor in both the highway and the vehicle will be the transportation needs of the communities. We are not in a position to say today what we shall build, nor should we encourage the public to believe that we should curtail beyond a certain reasonable limit the capacity or the type of truck that will be or should be used on the highway.

Mr. Goldbeck covered his subject in such a thorough manner that I can add only that the word drainage has come into such common use in this country that I am afraid it has been misused. I am satisfied that engineers are awakening to the fact that the real necessity is not to take the moisture out of a road, but to keep it out and away from the road. If we do that, we will have dry surfaces, in a short time dry subgrades, and in a little while longer we will not hear any more talk about the size of the truck that will use the road, because the dry road will stand the weight. I am satisfied that so far as is possible in reason, without handicapping the needs of the communities, we should attempt to protect the roads that we have already constructed until we are able to build the roads to meet a greater need.

R. A. MEEKER:—Some things have been left unsaid.

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It is true that drainage is an essential feature in the construction of all roads; however, sometimes an engineer is condemned for faulty drainage when it is not his fault. The American public has an idea that it is only necessary for us to build a road and that we can then go away and forget it. It is just as essential that a road should be maintained and carefully watched as that any motor vehicle should be carefully maintained. Where would the motor truck be if it were not maintained properly? Along the same line of reasoning, very many people condemn roads. The foundation of a concrete road should be resilient to a certain extent. There is no resiliency in a slab of concrete. It is "as hard as a rock." It will break under impact. It seems rather strange that in designing concrete roads we have neglected all that we learned in designing concrete sidewalks. No man would think of laying a concrete-slab sidewalk without carefully excavating the earth underneath and filling in with some pervious material such as cinders or sand, thus making a cushion for the slab, but who does that with concrete roads? The roads fail and then that type of road is condemned.

Some years ago one of our county engineers was taking up an old stone road. I suggested that he take everything out of the road, bring the subgrade to an elevation about 3 in. above the finish of the subgrade and then plow the whole thing from side to side. He doubted this. However, he tried it. Now there is a concrete road 3½ miles long that has no cracks in it except in two or three places, and those are due to neglect of the drainage. The underdrains were put in and the road was properly drained, but they were broken and nobody repaired them. When the underdrains were examined they were found to be mashed in.

A MEMBER:—Mr. Williams states that experience has proved that an asphalt surface will not stand up under heavy truck traffic. The service records of asphalt pavements throughout the country, on both rigid and non-rigid bases, are contrary to this assertion. Like any other pavement, the serviceability of asphaltic types depends largely upon the support furnished the pavement from below. Mr. Williams apparently pins his faith to the beam strength of rigid pavements and states that asphalt surfaces aid a concrete base but slightly in sustaining beam loads. In this connection it is rather significant that many miles of rigid pavements which have failed under heavy motor-truck traffic, are now being suc-

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cessfully salvaged as foundations by laying an asphalt wearing course upon them. This, I believe, is the present practice in Maryland. As a matter of fact, asphalt paving mixtures not only possess considerable beam strength but greatly increase the beam strength of the rigid types when subjected to impact, which is recognized as the most destructive traffic agency on a pavement. This fact has been demonstrated by recently conducted tests the results of which were published in the *Engineering News-Record* for Dec. 30, 1920.

I believe that if as much attention were paid to the suitable preparation of subgrades as to the increase in the massiveness and strength of pavement design, our paving problems would be solved much more quickly and economically. It is not believed that rigidity in the design of pavements is any more logical than in the design of motor trucks. The motor truck itself, as well as the load it carries, is logically protected from the shocks of traffic by rubber tires and springs. No one would for a moment believe it advisable to construct a perfectly rigid truck and increase its massiveness of design to withstand the destructive agencies of traffic. Why then should such practice be recommended in the construction of highways?

D. C. FENNER:—Mr. Williams' paper states that on the heavy-capacity trucks the wheel-load runs from 4 to 8 tons, which is supported upon a tire area of 48 sq. in. Partly to satisfy my own curiosity in that respect, I took a 7½-ton truck equipped with 14-in. rear tires, placed the truck on a concrete slab and reduced the pressure to 105 lb. per sq. in.

H. W. SLAUSON:—One of the interesting features of Mr. Goldbeck's paper is his reference to the effect of differences in inflation pressures of pneumatic tires, in regard to impact pressures. I understood him to say that there was no difference whether the tires were pumped to 110 or 160 lb. per sq. in. My interpretation of the effect of impact has been the absorption by the tire of the hammer-blow struck by the loaded wheel when it travels through the air and strikes the road. We all think that an under-inflated pneumatic tire rides more easily. If that is the case, why is the impact the same? Are we wrong in thinking that an under-inflated tire rides more easily, or is there a difference that is not observed with the truck?

MR. GOLDBECK:—An under-inflated tire does ride more easily and, as a matter of fact, the tests do show a some-

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what higher impact for the more highly inflated tires. In regard to the theory of impact and what we mean when we speak of impact, we know that there is an old law in physics which says that a force is equal to the mass times the acceleration. This means that if we have a weight at rest whose mass is M, and we act upon that weight with a force F, thereby increasing the velocity of that weight from zero up to a certain maximum velocity in a given time, we will have accelerated or changed the velocity and that is this quantity A. We can see readily that the shorter the time required to change the velocity from zero up to a certain maximum, the higher will be the quantity A, because the acceleration is equal to the time-rate of change of velocity. The higher the acceleration is, the mass remaining constant, the greater the force exerted on the road surface will be.

What do we have when a truck tire strikes the road surface? We will say that the tire is just about to fall from one level to a lower level. The tire strikes the road surface and begins to flatten out. At this instant there must be a reaction created between the road and the tire. The flatter it becomes the greater that force will be. In other words, we have a variable force acting between the tire and the road surface, depending upon the extent to which the tire is flattened out. Suppose one tire flattens out much more than another, in bringing that load to rest. This generally means that there is a longer time required to bring that load to rest; a longer time means smaller acceleration, because acceleration is equal to the velocity divided by the time. The longer the time is the smaller this quantity A will be, and the smaller the acceleration; so, the theory shows that the greater the deflection of the tire, the longer will be the time required to bring the unsprung weight to rest and the lower the acceleration, and, from this formula, the lower will be the force exerted on the road surface.

That is not the only force exerted on the road surface in the case of a truck wheel because, when a truck wheel strikes the road surface, it is influenced not only by the force of gravity but by the compression in the spring; so, we must add to that the quantity C, which is the amount of compression existing in the spring at the time the truck tire comes to rest. This whole question of impact is merely one of the time required to bring the weights to rest in a vertical direction.

CHAIRMAN ALDEN:—The curves did show a difference between 110 and 160 lb. per sq. in. It is not negligible.

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This question of the time element and the yield is a very important one.

W. E. WILLIAMS:—From some of the statements made, this audience appears not to be closely in touch with the men who are building and supervising roads. Road engineers would like to build the very best roads in the first instance and to be able to say that they are permanent highways, but the cost will not permit that. When we began to build railroads in this country, one railroad built on this basis was an example of a splendidly constructed road, but it nearly bankrupted the country.

If one goes into the history of the financing of our railroads generally, one will find that what I have said about cheaper roads and large mileage is true. Legislation is bound to be passed to do exactly what I have outlined about limiting the heavier loads.

In regard to the matter of upkeep, Mr. Meeker had a clear idea of what a road really requires. Let me go a little further. The railroads have been long enough in this country to have had technical attention that represents 25 to 50 per cent more work than the highways have had. A railroad cross-tie can be treated to extend its life, but a time arrives when the cost of that cross-tie is not a good investment. It is better, at some cost, to renew it and to put in a cheaper cross-tie. The same thing is true in the matter of the first cost of building highways. We had better build a cheaper road and put on watchmen to keep off the destructive loads. A 7½-ton concrete-slab road costs about $40,000 per mile in our region. It is better to keep repair gangs in maintenance service than to increase the first cost for a stronger road.

In regard to impact, all of the talk here about impact has referred to the road after it has broken down. When we have a fault, say a 2-in. drop, it is no longer a road. Send for the section gang and do not calculate that tires or anything else will save it.

It matters not how much area of tread-contact tires have on the road; it is the total load on the axle of the wheel that counts. For brick surfaces and concrete surfaces withstand more pressure per square inch than will the rubber of the tire. It has been related here how a broken-down road was saved by putting on some asphalt. That did some good but it would have been better if a wire brush had been run across its surface, if it had been thus scraped clean and if concrete had been added. Some of the experiments that the Government is conducting relate to things long well known in civil engi-

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neering, yet this may be necessary to bring the facts sharply to the attention of the public.

As to a porous sub-base, it is a fine thing, but is it the best thing? What we are after is the best thing for the least money. To use a 4, 5 or 6-in. sub-base of sand or any other porous material, is not a good investment unless that material is easily obtainable. Where rock and sand must be hauled many miles, they are not a good investment. It is better to increase the depth of the concrete block at the same cost as that of the porous material and thus get the strength benefit of the square of the depth.

S. W. WILLIAMS:—We are not building roads in this Country with any knowledge of traffic. We went before the Legislature of Ohio 2 years ago and asked for authority to employ a traffic and sub-soil engineer. The matter was so little understood that we could not get the necessary authority. The average road in this country is sold from the standpoint of the material salesman on the job, and not from the standpoint of the traffic. I believe that all will agree with me that 80 per cent of the roads in this Country have not been built with a knowledge of traffic conditions. We are building in some places away beyond the needs of the traffic. In other places we are building roads that do not meet the needs of the traffic. We should build roads that will take into consideration the traffic, regardless of what material the roads are built.

A MEMBER:—I cannot agree with one statement Mr. Williams made. He says, "A concrete-slab road about 8 in. thick and of a uniform depth across the road, perhaps with an increased thickness of integral supporting curb-block on the edges in some locations, is the type of road that should be built in this country." Again he says, "In my opinion the automobile vehicle world will profit by laws that prohibit anything above a 5-ton load."

The limit for any concrete road now built is about 8 in. That certainly is the practice. There are a few stretches in New Jersey and one that I know of in Ohio that are 10-in. roads. The most prominent we see out West is the Wayne County road. These roads have been standing up under the most severe loads. I believe that an 8-in. concrete road need not be restricted to 5-ton loads. There are very few road failures, compared with the enormous mileage of 8-in. concrete slabs under loads heavier than 5 tons.

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W. E. WILLIAMS:—In Clayton County, Iowa, the citizens realized that their money was not sufficient to build high-class roads. They arranged to have men go out over the roads after every rainstorm and fill up the ruts by using drags and other tools. By filling up the ruts immediately after rains they keep the roads in such condition that there is a greater average use of the motor vehicle and better general highway service. That only accentuates the necessity of watching and keeping the roads in repair. We must do that. Automobile service in this Country is limited to the good roads. The traveling man does not use an automobile in soliciting the country trade on account of bad roads. If we had a wider range of hard roads, the use of motor vehicles would be increased greatly.

A. F. MASURY:—The new seismograph designed by Frank Pampinella and me, although simple in construction, records a very complete and accurate history of the comparative vibration of a truck or automobile chassis

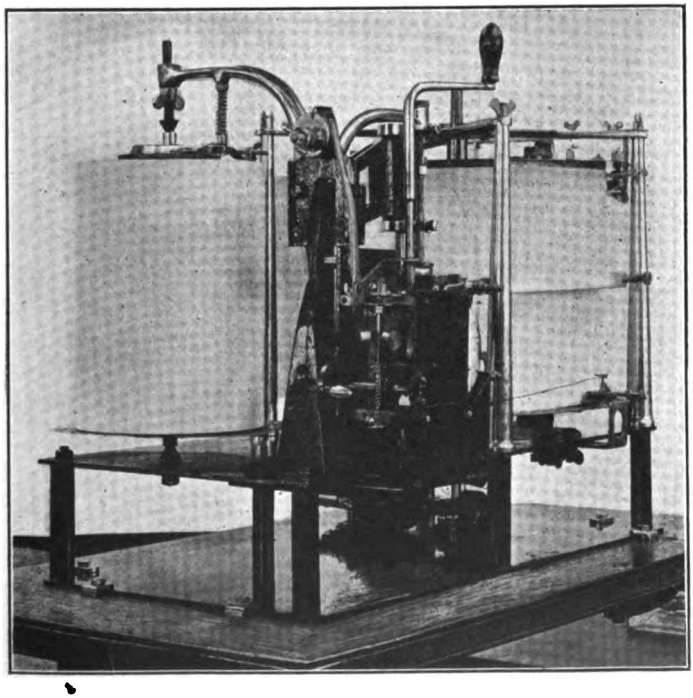

FIG. 1—A NEW FORM OF VEHICLE SEISMOGRAPH

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under the action of different types of spring and axle-load distribution. Differences in spring action, too slight for human detection, are accurately compared. With such a means of comparison, engineers are enabled to choose with accuracy spring suspensions that will transmit the least vibration to the "sprung" portion of the chassis. The 1915 machine has been improved and developed into the present seismograph. It is sensitive

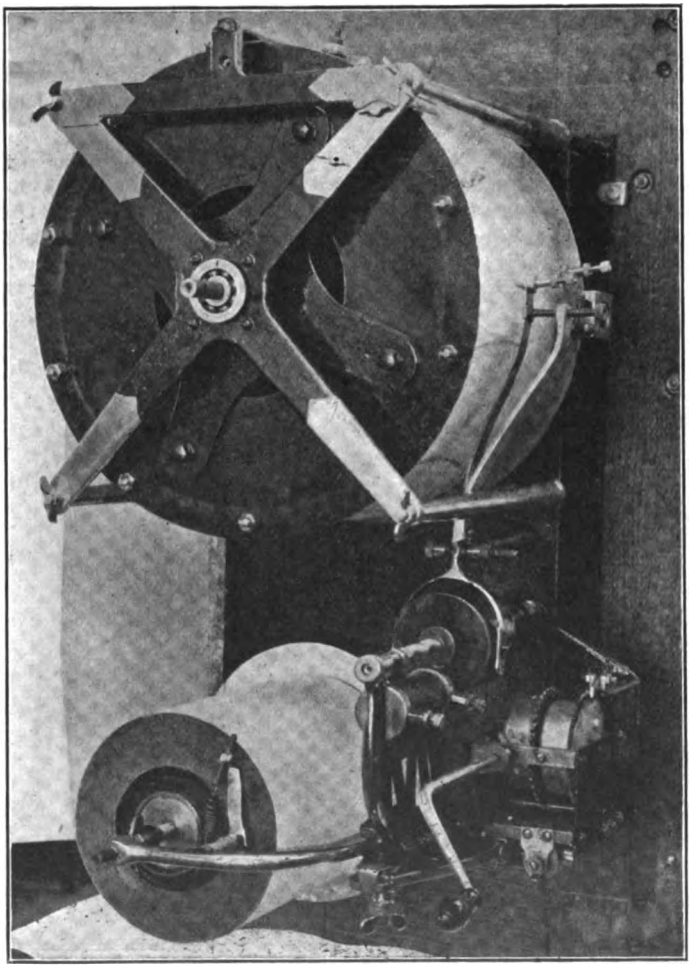

FIG. 2—VIEW LOOKING DOWN ON THE SEISMOGRAPH

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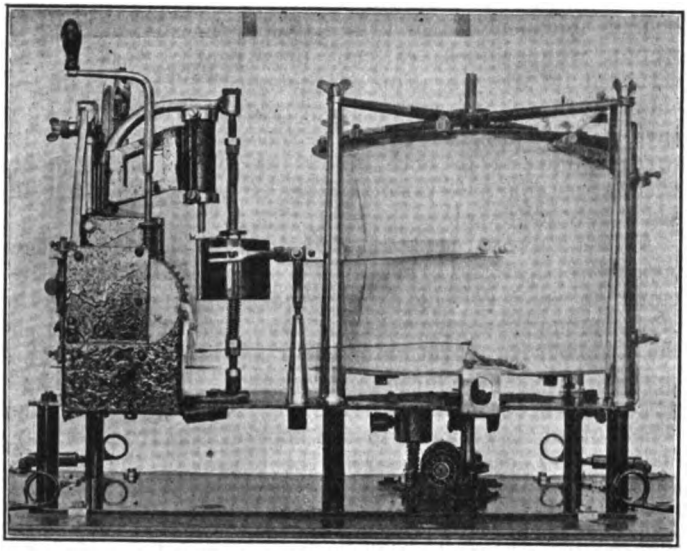

FIG. 3—SIDE VIEW SHOWING A PORTION OF A RECORD AS TRACED BY THE PENCIL

to the slightest vibration and records movements that are far beyond human detection. Figs. 1, 2 and 3 and the description give an idea of the construction and operation of the instrument.

Mounted in a rigid steel frame is a metal drum 12 in. in diameter and 9 in. high, driven through a double-reduction worm and gear giving a ratio of 32 to 1. The worm shaft is driven by a flexible speedometer shaft from the front wheels, and turns the drum at the rate of one revolution per mile of travel of the truck. On the upper edge of the drum are 10 cams, equally spaced, which trip a pencil-holder and record tenths of a mile on the paper which is rolled on the drum. The paper is fed to the drum from a spool at the opposite end of the frame. A phonograph motor is mounted near the recording drum and operates a pencil which marks periods of time on the record. This motor can be governed to record intervals of ½ or 1 min. as desired.

In addition to these two pencils there are two stationary pencils which rule horizontal guide lines on the paper near the top and bottom edges and equidistant from the center. The seismograph pencil is held on a light spring arm pivoted on single-point bearings. On the opposite

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end of this pencil arm is a slotted fork surrounding a weight which slides vertically on a central post and is actuated by the vibration of the truck. The weight is supported by a coil spring from below and a lighter coil spring above prevents excessive rebound. The weight is further damped in both directions by an air dashpot with adjustable outlets so that the damping effect can be accurately adjusted.

As the weight moves up and down, the pencil at the opposite end of the arm leaves a series of marks on the paper on the revolving drum. The proportionate length of these marks, measured from the guide lines, indicates the comparative vibration of the unsprung portion of the chassis. The entire mechanism is enclosed in a glass case with sliding doors in both the top and the sides. The seismograph is screwed to the floor of the truck or car body in any location desired, the length of the flexible driving-shaft varying with the location. A lever below the glass case throws the worm gearing out of mesh, so that the record can be stopped or started at will.

Fig. 4 shows a representative record from the seismograph as used on a 5-ton chassis, the seismograph being mounted directly over the rear axle. The numbers refer to the road conditions encountered, these being listed underneath the illustration. The notched line at the top of the record was made by the mileage pencil and indicates tenths of a mile. The two horizontal lines above and below the seismograph record are guide lines made by the stationary pencil and are used to measure the distance traveled by the seismograph pencil. This is preferable to a central guide line, which would be covered in many places by the seismograph record. The notched line at the bottom of the record is made by the time pencil and indicates minutes elapsed.

The company I represent has been using this instrument for some time in measuring the relative vibration in trucks equipped with standard spring-shackles and a new rubber-cushion spring-support. It has been found that over comparatively rough roads the difference is very noticeable to anyone riding on the truck, but on smooth roads the seismograph recorded a series of vibrations on the standard chassis much greater than those on the chassis equipped with the rubber cushions and which was not noticeable to observers on the trucks.

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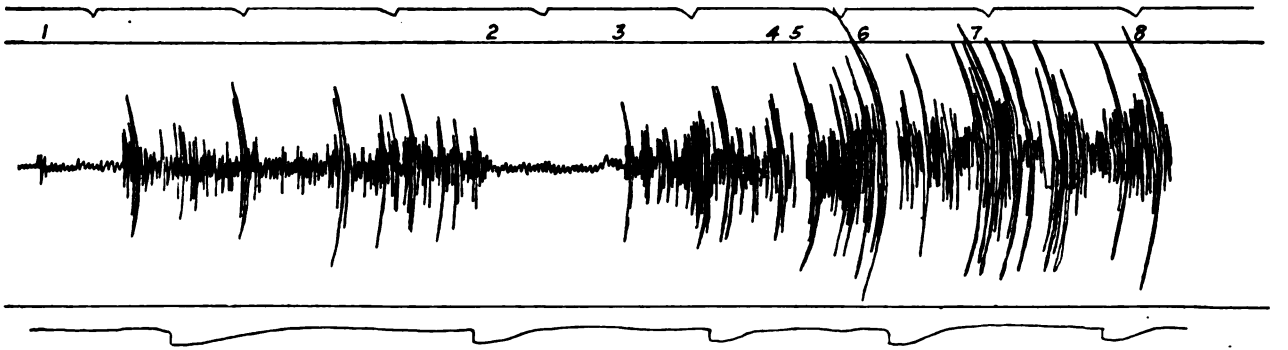

FIG. 4—A TYPICAL RECORD GIVEN BY THE SEISMOGRAPH

From 1 to 2 the Truck Was Traveling over Rough Asphalt at a Speed of 15 M.P.H., between 2 and 3 the Speed Was Reduced to 6 M.P.H. and from 3 to 4 the Speed Was Increased Again to 15 M.P.H. The Break in the Record between 4 and 5 Indicates the Stoppage of the Truck. Between 5 and 6 the Truck Was Traveling over Rough Stone Blocks on a Quay. At 6 All Four Wheels Ran over a 3-In. Obstruction at a Speed of 8 M.P.H., at 7 the Right Wheels Only Passed over a Similar Obstacle at 8 M.P.H. and at 8 the Left Wheels Went over a 3-In. Obstruction at the Same Speed

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AERONAUTIC PROPELLER DESIGN

By F W Caldwell[1]

It is of course impossible to consider propeller design very much in detail in a paper of this nature. It can be said, however, that the airfoil theory, in connection with the inflow theory, has given very good results and proved exceedingly valuable for the aerodynamic design of propellers. Both theories, however, in the present state of knowledge, must be applied with a number of empirical factors.

Propeller-design theories and the subject of aerodynamics are discussed mathematically, as well as the elements governing the best propeller diameter for obtaining the highest thrust. Consideration is given in detail to steel, adjustable-pitch and reversible propellers as well as to those made of laminated construction consisting of sheets of paper fabric impregnated with bakelite as a binder. The mathematical considerations that apply to propellers when reversed in flight, the time and distance required to stop when landing and the propeller stresses are enumerated and commented upon.

The tendency of propeller design is discussed and the methods of propeller testing are described. The paper is copiously illustrated.

The tendency of propeller design in the United States, France and Germany has been toward very narrow blades with extremely narrow tips. The British have adopted narrow tips but have not gone as far in making the main portion of the blade narrow with respect to the diameter. The use of these blades has been arrived at principally by the method of trial and error; experience having demonstrated that such blades give better performance in climbing and at top speed. The inflow theory, however, gives an indication that it is better with fast turning low-pitch propellers to use a somewhat narrower blade than has been customary on account of the fact that the optimum angle of attack for the various stations approaches more nearly the angle of attack for the best L/D. This is brought out by the chart in Fig. 1.

In speaking of the width of propeller blades as a whole, it has become customary to refer to the ratio of the tip

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radius to the maximum blade width as the aspect ratio. This aspect ratio has increased in our best propellers for fast turning engines from about 5 to about 7. In considering individual elements of the blade, however, the ratio of the sum of the blade widths to the periphery at the station under consideration is usually taken as a criterion of blade width and is written $B/2\pi R$. This quantity is called the breadth ratio and is analogous to the ratio of developed area to disc area used by naval architects. Fig. 2 shows the coordinates of an airfoil section of British origin adopted for use on the Army propellers. As the camber ratio is varied at different stations along the propeller blade the section is generated from that shown in Fig. 2 by varying all the ordinates in proportion to the maximum thickness. The plan form of propeller blades has to be varied considerably according to the service of the propeller and the material for which it is designed. The upper portion of Fig. 3 shows a very good plan form, originated by H. C. Watts, of the British

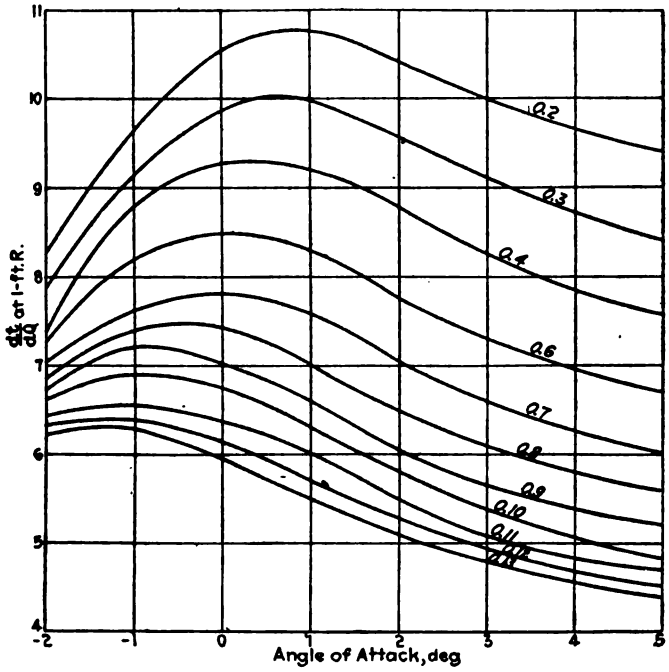

FIG. 1—OPTIMUM ANGLE OF ATTACK FOR VARIOUS BREADTH RATIOS FOR A SECTION HAVING A CAMBER OF 0.09

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Air Board, which is very successful up to tip speeds of about 800 ft. per sec. and up to about 400 hp. Up to this speed and power this plan form is very satisfactory for wooden propellers in connection with the thickness ratios shown in the lower part of this illustration. For higher speeds and horsepower a similar plan form may be used, but these thicknesses will have to be increased in most cases. Fig. 4 in the upper section shows a plan form adopted by me for use in Micarta propellers while the lower portion shows a form recommended for steel propellers having an aspect ratio of 9.

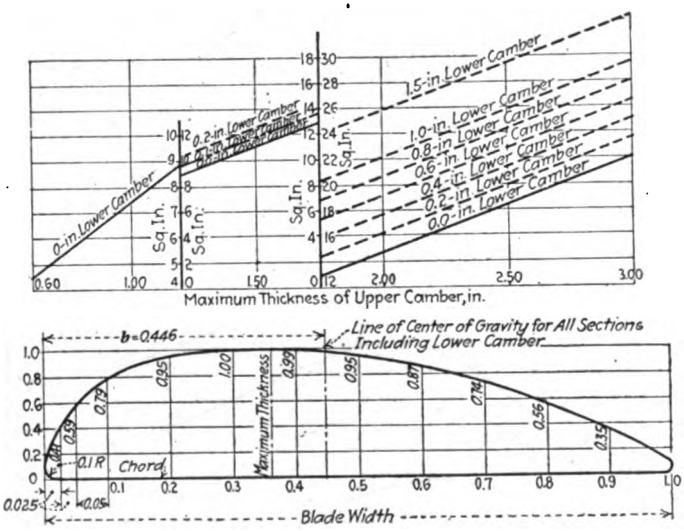

FIG. 2—COORDINATES OF A BRITISH AIRFOIL SECTION ADOPTED FOR USE ON ARMY PROPELLERS

For reversible propellers the above plan forms can be used as far as the variations in blade width are concerned, but it is very desirable for reversible propellers to space the centers of gravity for all the sections along a radial line perpendicular to the axis of rotation. If this is done the centrifugal moments are entirely eliminated except insofar as they are produced by the deflection of the blade. This arrangement, however, gives stresses which are symmetrical when the propeller is reversed. In other words, when the propeller is reversed the deflection still produces a centrifugal restoring moment, and since there are no initial centrifugal moments the stresses are similar to those in the forward pitch

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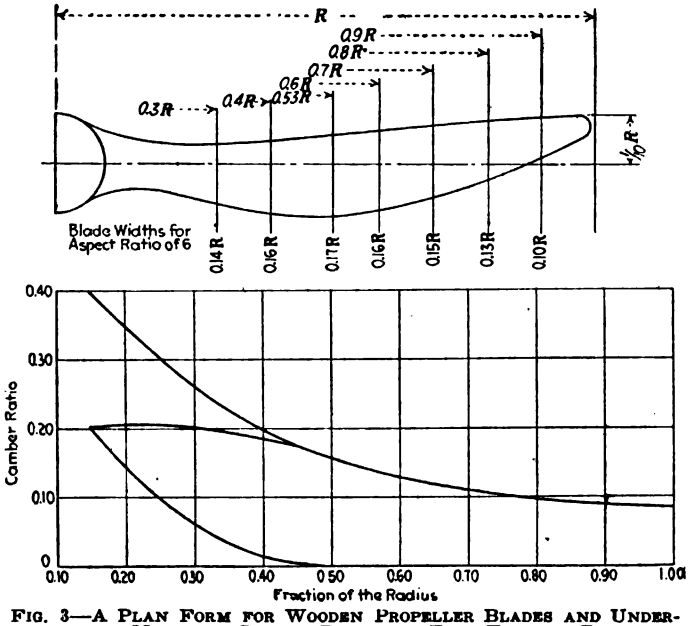

FIG. 3—A PLAN FORM FOR WOODEN PROPELLER BLADES AND UNDERNEATH THE MINIMUM CAMBER RATIO FOR THIS FORM OF PROPELLER AT VARIOUS STATIONS

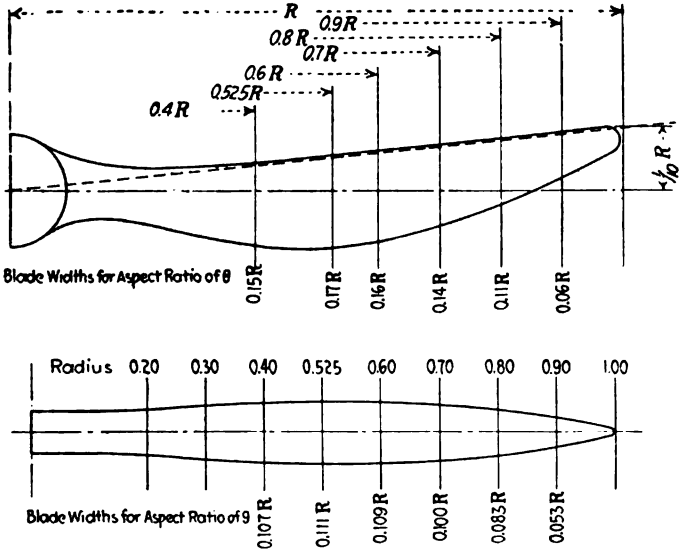

FIG. 4—PLAN FORM (ABOVE) FOR A MICARTA PROPELLER BLADE AND (BELOW) ONE FOR A BLADE MADE FROM STEEL TUBING

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position. This arrangement does not remove all of the torsional moments from centrifugal force as can be seen from the discussion of reversible propellers.

In the case of engines of small horsepower considerable advantage in performance can be obtained by varying the plan form to suit the particular needs for which the propeller is to be used. For example, the straight leading edge has a torsional moment resulting from air pressure which tends to increase the pitch and a torsional moment resulting from centrifugal force which tends to increase the pitch. This plan form is especially suitable to ceiling propellers as there is comparatively small drop in the speed of the engine in climbing from the ground level to the ceiling, owing to the gradual decrease in pitch as the thrust decreases. The propeller is, however, not well adapted to meet the conditions of climbing and top speed near the ground, as the pitch decreases at top speed, causing a greater increase in revolutions between the climbing condition and the top-speed condition. One plan form is very well suited for climbing and top-speed conditions, but is not very well suited for ceiling. This plan form and elevation give an arrangement of the center of gravity line which causes the pitch to decrease as the result of the thrust and also as the result of revolutions. As the thrust decreases in going from the climb to top speed the pitch is increased, so that the engine shows a comparatively small gain in revolutions at top speed. The form is not very well suited for ceiling, since the pitch increases as the thrust drops off at ceiling, causing great loss of revolutions near the ceiling. Another plan form which is especially well suited to Micarta propellers as applied to supercharged engines shows a decrease of pitch as the result of the thrust and an increase of pitch as the result of revolutions. As a result, there is a very small gain in revolutions between the top and the climbing speeds. With the ordinary type of engine there is a considerable decrease in revolutions during the climb between the ground and ceiling, but with the supercharged engines there is an increased pitch at high altitude as the result of the drop in the thrust, and also as a result of the increase in revolutions, which is an exceptionally valuable feature. The French have shown considerable skill in the choice of a plan form to accomplish given results by this method which has been successful with small engines. With engines of 400 hp. and over, however, it is not always possible to choose

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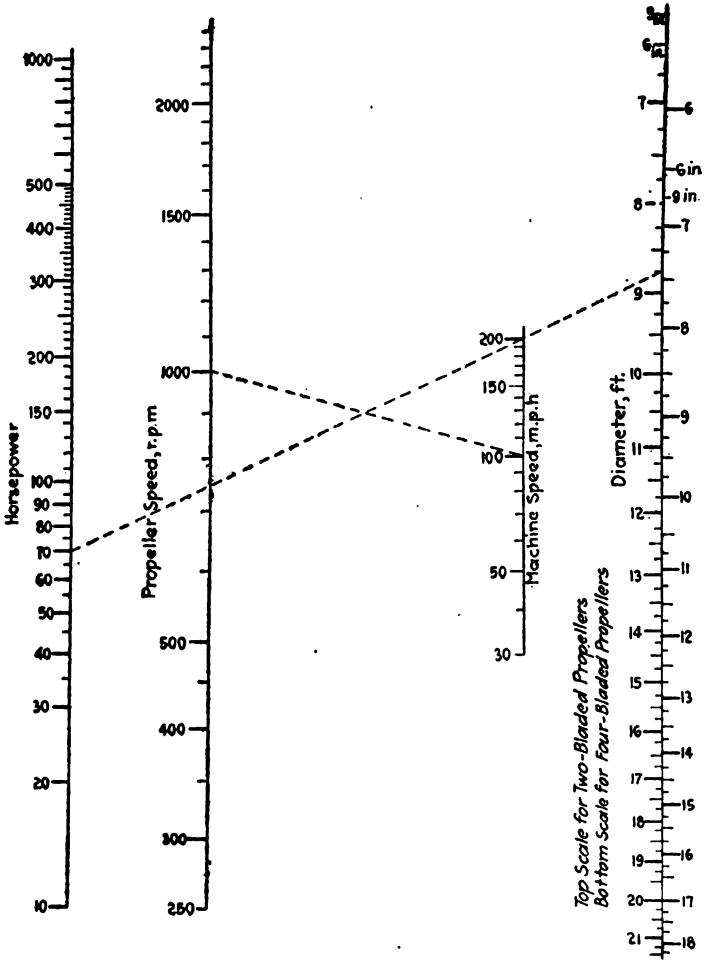

FIG. 5—NOMOGRAM FOR DETERMINING THE BEST PROPELLER DIAMETER FOR A GIVEN COMBINATION OF HORSEPOWER AND ENGINE AND PLANE SPEEDS AT THE GROUND

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the plan form in view of the performance as there is some difficulty in obtaining a smoothly running propeller free from flutter for these large engines.

Fig. 5 shows a nomogram worked out by Mr. Watts from which the best diameter for given horsepower and engine and plane speeds at ground level can be obtained. This nomogram is very satisfactory for use in connection with the wooden plan form shown in the upper part of Fig. 3, with an aspect ratio of 6 but for this plan form with other aspect ratios and for other plan forms the nomogram is not applicable.

A model test on one of the propellers adopted by Dr. Olmstead showed a maximum efficiency of 88.5 per cent, which is the best result I know of in a practical propeller. Unfortunately, structural considerations have not permitted a very wide application of this type of propeller. It appears probable that this type will be very successful when reduction gearing is applied to very large engines, and it ought to be extraordinarily good for dirigible balloon work.

It is, of course, impossible to go into propeller design very much in detail in a paper of this kind. It may be said, however, that the airfoil theory in connection with the inflow theory has given some very good results and proved to be very valuable for the aerodynamic design of propellers. Both theories have to be applied in the present state of knowledge with a number of empirical factors determined in practice.

Propeller Theories and Aerodynamics

The basic theory of propellers, at least as far as aircraft propellers are concerned, has been built upon the elemental or strip theory which is due to Drzewiecki. This method of studying the propeller consists of dividing the blades up into zones of given lengths as shown in the upper part of Fig. 6, and assuming that each zone is an airfoil section having certain resultant pressure coefficients at various angles of attack, and a given direction of pressure at each angle of attack. The conception of angle of attack and the direction of resultant pressure are shown in the lower left corner for a given section. In studying propellers by this method, the work absorbed and delivered by each of the sections is computed and the whole added up to give the total work absorbed and delivered. The efficiency obtained by this method was observed at the start to be far too high and

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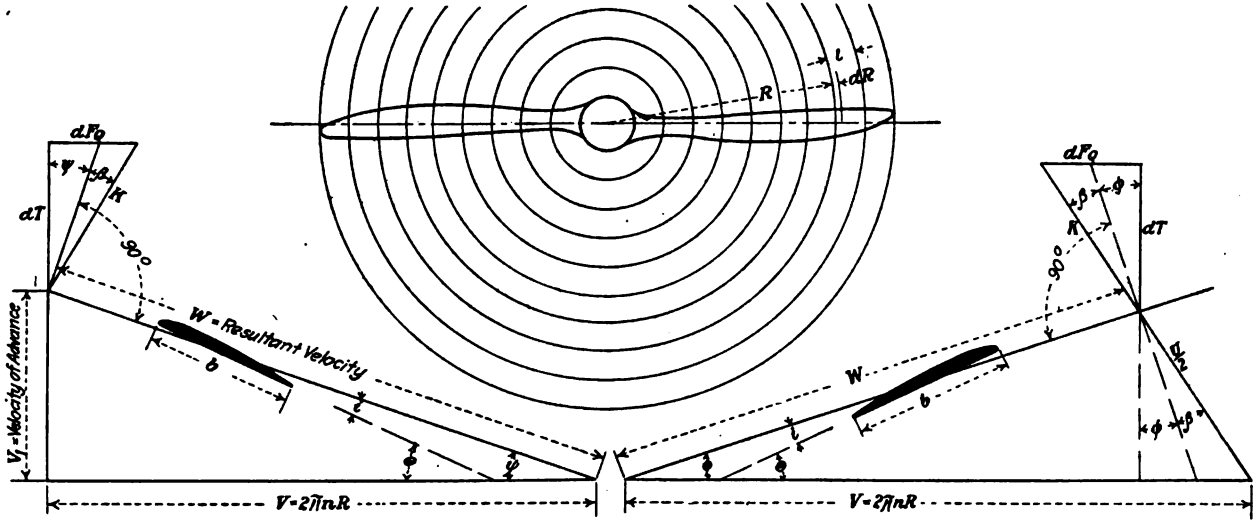

FIG. 6—AT THE LEFT THE ORIGINAL DRZWIECKI ANALYSIS OF THE STRIP THEORY OF PROPELLERS WITHOUT INFLOW, IN THE CENTER AN ILLUSTRATION OF THE STRIP THEORY OF PROPELLERS AND AT THE RIGHT AN ANALYSIS OF THE VELOCITIES AND FORCES ACTING ON AN ELEMENT OF THE PROPELLER BLADE ROTATING AT A FIXED POINT

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the method was supplemented by the addition of the inflow conception in which the slipstream and race rotation created by the propeller are taken into account.

If v denotes the resultant velocity imparted to the air by an element of a propeller blade and M denotes the mass of air passing through the annulus generated by this element, in a unit of time, then the resultant pressure P on the element is equal to M times v. This is simply the law of impact resulting from fluid passing through the propeller at the disc. It should be borne in mind, however, not only that the resultant pressure P is equal to the product $M\ v$ but that the direction of the resultant pressure P must be opposite to the direction of the resulting velocity v, since action and reaction are equal and opposite. Based on this conception, the mathematicians have gradually evolved the theory that has been worked out in a most complete form by Dr. George de Bothezat.[2]

It would go beyond the scope of this article to go into the derivation of these theories in a very comprehensive manner, but I have tried to give the simplest possible discussion of this theory with the resulting equations. The simplest case of the inflow theory applies to the propeller at fixed point and the diagram for this condition is shown in the lower right corner of Fig. 6. The width of a single blade at a radius R from the axis is denoted by b and the sum of the width of all of the blades is denoted by B. K in the diagram represents the total resultant force on the blade elements and k the resultant pressure coefficient, so that $K = \rho/g\ (kSW^2)$, but the area of the element of all of the blades is $B\partial R$, so that

$$K = \rho/g\ (kB\partial RW^2)$$

$$W = \tfrac{1}{2}v[\cos(\Phi + \beta)\ /\ \sin\Phi]$$

$$K = \rho/g[kB\partial R(\tfrac{1}{2}v)^2\{\cos^2(\Phi + \beta)\ /\ \sin^2\Phi\}] \qquad (1)$$

From the impact theory, however, $K = v\partial M$. Since ∂M is the mass of air flowing through the annulus per unit of time

$$\partial M = \rho/g \cdot \tfrac{1}{2}v \cos\ (\Phi + \beta)\partial A$$

the inflow velocity being taken as one-half the outflow. $\partial A = 2\pi R \cdot \partial R$; hence

$$\partial M = \rho/g \cdot \tfrac{1}{2}v \cos\ (\Phi + \beta) \cdot 2\pi R \cdot \partial R$$

and

$$K = \rho/g[\cos\ (\Phi + \beta) \cdot 2\pi R\partial R \cdot v]$$

$$= \rho/g(\tfrac{1}{2}v)^2[\cos(\Phi + \beta) \cdot 2\pi R\partial R] \qquad (2)$$

[2] General Theory of Blade Screws by George de Bothezat, National Advisory Committee for Aeronautics Report No. 29, 1918.

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Equating (1) and (2) and simplifying we get

$$kB[\cos(\Phi+\beta)/2\sin^2\Phi]=2\pi R$$

or

$$k(B/2\pi R)=2\sin^2\Phi/\cos(\Phi+\beta)$$

This equation permits of a ready solution for ϕ when $B/2\pi R$, k and β are known. The equation is represented graphically by the nomograms in Fig. 7. To find ϕ, connect k and $B/2\pi R$ and find the product on the scale C. Rotate the straight-edge about this point until the value of ϕ, read on the ϕ scale, plus the known value of β, equals $\phi+\beta$, read on the $\phi+\beta$ scale. It can be shown that

$$W=2\pi nR(\cos\Phi-\sin\Phi\tan\beta)$$

so that

$$K=\rho/g(K_1B\partial R)\times(2\pi nR)^2\times(\cos\Phi-\sin\Phi\tan\beta)^2$$

and since

$$\partial t=K\cos(\Phi+\beta)$$
$$=\rho/g(kB)\times(2\pi nR)^2\times(\cos\Phi-\sin\Phi\tan\beta)^2\cos(\Phi+\beta)\partial R$$

or

$$\partial T=\rho/g[K(B/2\pi R)\times(2\pi)^2\times N^2R^2\times(\cos\Phi-\sin\Phi\tan\beta)^2\cos(\Phi+\beta)\partial R$$

This can be written

$$\frac{\partial T}{\partial R}=\rho/g\left[\frac{\pi^2}{D_1}\cdot k\cdot\frac{B}{2\pi R}\cdot\left(\frac{R}{R_1}\right)^2\cdot(\cos\Phi-\sin\Phi\tan\beta)^2\cos(\Phi+\beta)\right]n^2D_1^4$$

If the quantity in the brackets be plotted against R/R_1 and integrated, we shall evidently find the value of the quantity T_c in the formula

$$T=\rho/gT_cn^2D_1^4$$

To simplify the calculation for thrust the expression $\cos(\phi+\beta)(\cos\phi-\sin\phi\tan\beta)^2$ has been shown graphically in Fig. 8 for various values of ϕ and β.

The torque coefficient Q_c can be computed in a similar way. The value of the ratio of thrust to torque takes a very simple form

$$\frac{\partial T}{\partial Q}=\frac{1}{R\tan(\Phi+\beta)}$$

It can be seen that the optimum angle for the best F_Q has been worked out for various values of $B/2\pi R$ and various angles of attack for a given airfoil section. It can be seen that the optimum angles for the best value of $\frac{\partial T}{\partial F_Q}$ is always lower than the angle of maximum L/D and approaches the angle as a limit as $B/2\pi R$ approaches zero.

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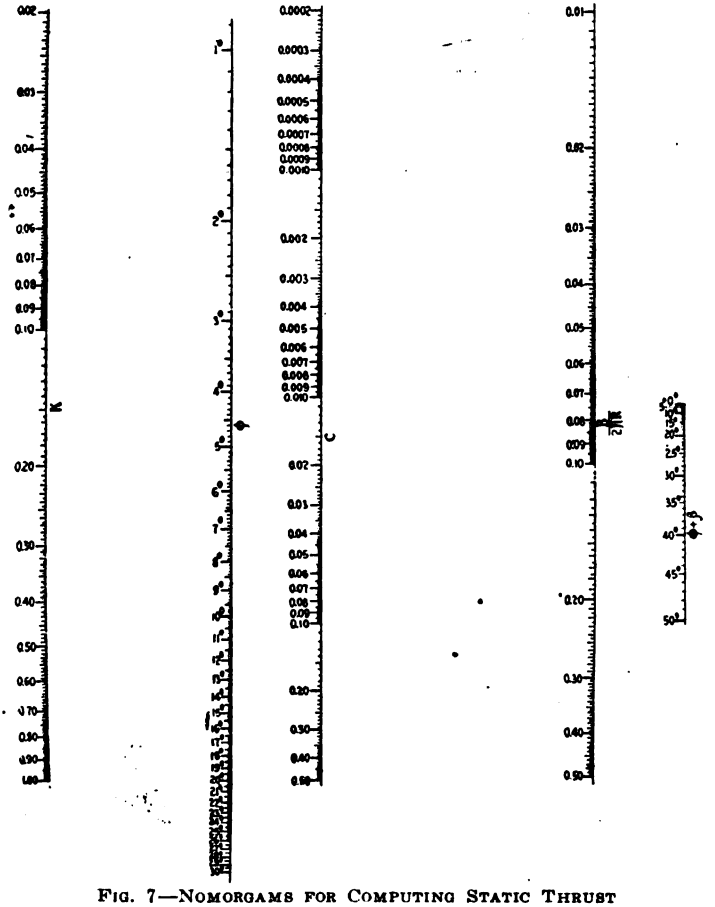

FIG. 7—NOMORGAMS FOR COMPUTING STATIC THRUST

At the same time the value $\frac{\partial T}{\partial F_a}$ approaches L/D as limit as $B/2\pi R$ approaches zero.

BEST DIAMETER FOR HIGHEST THRUST

The characteristic equation for thrust is

$$T = \rho/g T_c n^2 D^4$$

The corresponding equation for power is

$$P = \rho/g P_c n^3 D^5$$

Hence the thrust per unit of power is

$$T/P = [\rho/g\,(T_c n^2 D^4)] \div [\rho/g\,(P_c n^3 D^5)]$$
$$= T_c/P_c n D$$

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This is evidently a maximum when nD has its minimum value.

$$P = P_c n^2 D^2 = P_c (nD)^2 D^2$$

$$nD = (P/P_c)^{\frac{1}{2}} D^{-\frac{2}{3}}$$

Holding P constant and differentiating

$$\frac{\partial(nD)}{\partial D} = -\tfrac{2}{3}\left(\frac{P}{P_c}\right)^{\frac{1}{2}} \cdot D^{-\frac{5}{3}} = 0$$

and

$$\frac{\partial^2(nD)}{(\partial D)^2} = \tfrac{10}{9}\left(\frac{P}{P_c}\right)^{\frac{1}{2}} \cdot D^{-\frac{8}{3}}$$

Hence the condition for a maximum value of thrust in that the diameter should approach infinity as a limit.

For purposes of lifting, however, the formula for

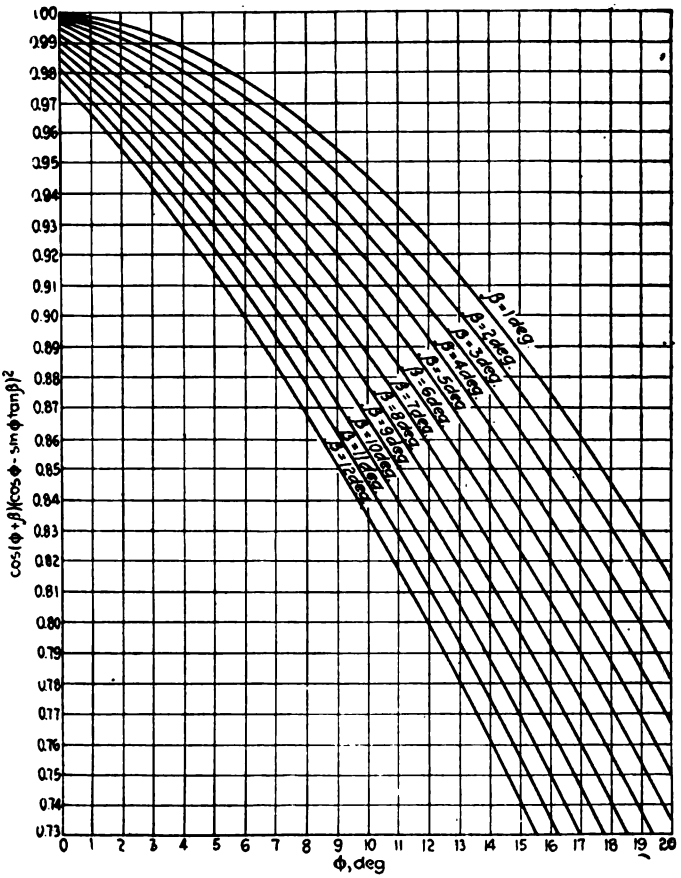

FIG. 8—GRAPHIC CHART FOR DETERMINING STATIC THRUST

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thrust must be modified as the weight of the propeller must be subtracted. In general the selection of proper diameter and speed of revolution will be a question of engineering judgment rather than of calculation, since structural features of the wings, landing gear, etc., must be taken into account. The calculation will serve only to show us what thrust can be realized and what revolutions are required when a maximum diameter has been chosen and the power available is known.

The object in introducing the above discusison is to show that there is no difficulty in obtaining sufficient static thrust for hovering with present aircraft, provided the powerplant and the propeller are modified to suit the conditions. The type of propeller described above would be of entirely too low pitch for level flight, however. To meet both conditions successfully an adjustable-pitch propeller will be necessary. The tests on the Hart adjustable-pitch propeller, whose development has been carried out under my supervision, have shown that we are now in a position to build satisfactory adjustable-pitch propellers without the introduction of any considerable increase of weight.

If this method is extended to apply to forward flight conditions, the formula for ϕ becomes

$$\frac{2\sin^2\Phi}{\cos(\Phi+\beta)} = k\cdot\frac{B}{2\pi R}\left[\frac{\tan\Psi}{\tan\Phi-\tan\Psi} + \frac{\tan(\Phi+\beta)\tan\Phi\tan\Psi}{\tan\Phi-\tan\Psi} + 1\right]$$

Fig. 9 shows a nomogram for the solution of the above quantities to be used in connection with Fig. 10. Thus, knowing k, β, ψ, we can find ϕ and knowing ϕ compute the thrust and torque coefficients as before.

The work absorbed by the element is evidently $\partial F \cdot 2\pi nR$, while the work delivered is $\partial T \cdot V_1$. Hence the efficiency is given by the equation

$$\begin{aligned} e &= \partial T\cdot V_1/\partial F_Q\cdot 2\pi nR \\ &= \tan\Psi/\tan(\Phi+\beta) \end{aligned}$$

It should be noted that the efficiency found by this method is always lower than the efficiency obtained by the simple Drzwiecki method illustrated in the lower left corner of Fig. 6 where

$$e = \tan\Psi/\tan(\Psi+\beta)$$

Micarta and Steel Propellers

A material which has shown great promise for use in propellers is manufactured by the Westinghouse Electric

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& Mfg. Co. under the name of Micarta. This material is made up of laminations or sheets of paper or fabric impregnated with Bakelite as a binder. In the case of the propellers the sheets are cut out in a form similar to the laminations of the wooden propellers, laid in a mold conforming to the exact shape of the finished propeller and heated for 3 hr. at a temperature of 350 deg. fahr., and under a pressure of about 1000 lb. per sq. in. The mold is provided with a stripping feature which greatly facilitates removing the finished blades.

Propellers made in this way are finished complete when

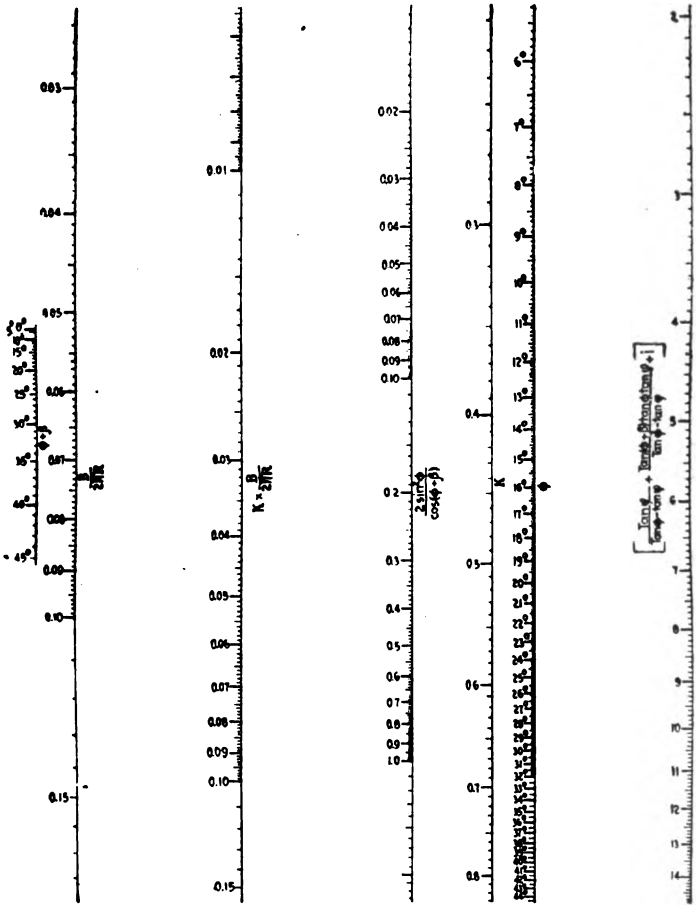

FIG 9—NOMOGRAMS FOR COMPUTING DYNAMIC THRUST

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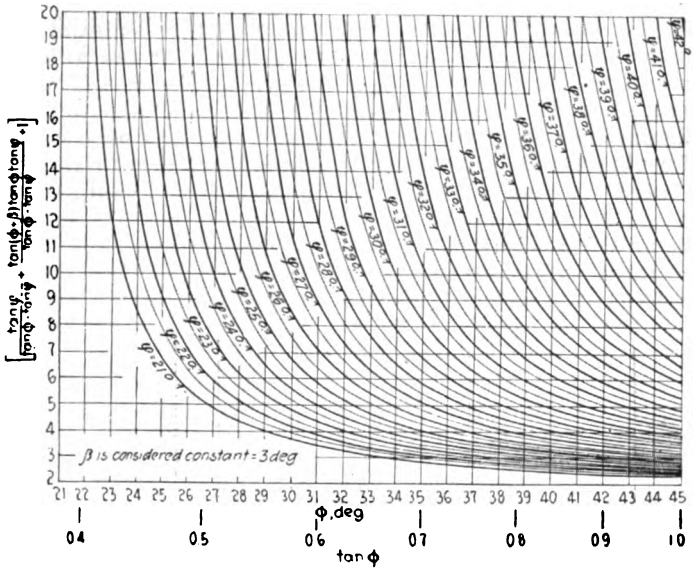

FIG. 10—GRAPHIC CHART FOR COMPUTING DYNAMIC THRUST

molded, and are bored for a hub in such a way as to correct any small inequalities in the density of the material which might lead to imperfect balance. The type of hub used is a cylindrical sleeve provided with four keys, a small flange on one end and a nut and loose flange on the other. The density of Micarta is about 1.35, so that the material itself is considerably heavier than wood. The additional weight is usually just about offset by the saving in weight of the hub construction. Two physical properties of Micarta which make it especially suitable for propeller construction are its great flexibility and the fact that it does not readily take up harmonic vibration. It has the additional advantage over wooden propellers that there is no tendency to split, and the grain can be put in any desired direction. Since the crushing strength is very high it is possible to drive direct by keys, without resorting to the usual construction of flanges and bolts.

Where Micarta propellers are used it appears that it will be possible to dispense with the metal hub altogether, provided the single key used at present as in the S.A.E. Standard shaft-end is replaced by four keys. The material is especially well suited to adjustable-pitch and reversible propellers, in that it permits of very simple and light connection between the blade and the hub of the

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propeller. It is anticipated that the reversible propeller with Micarta blades will be considerably lighter and more durable than the same type propeller with wooden blades, and will probably be less expensive.

At present a number of Micarta propellers are in service on the Liberty engine with very satisfactory results. I have designed a Micarta propeller for use on the Liberty engine with the USD-9 airplane. This propeller is laid out in such a way that the centrifugal moment produces a torsional effect tending to increase the pitch, while the thrust load produces a torsional moment tending to decrease the pitch. Thus, when the propeller is

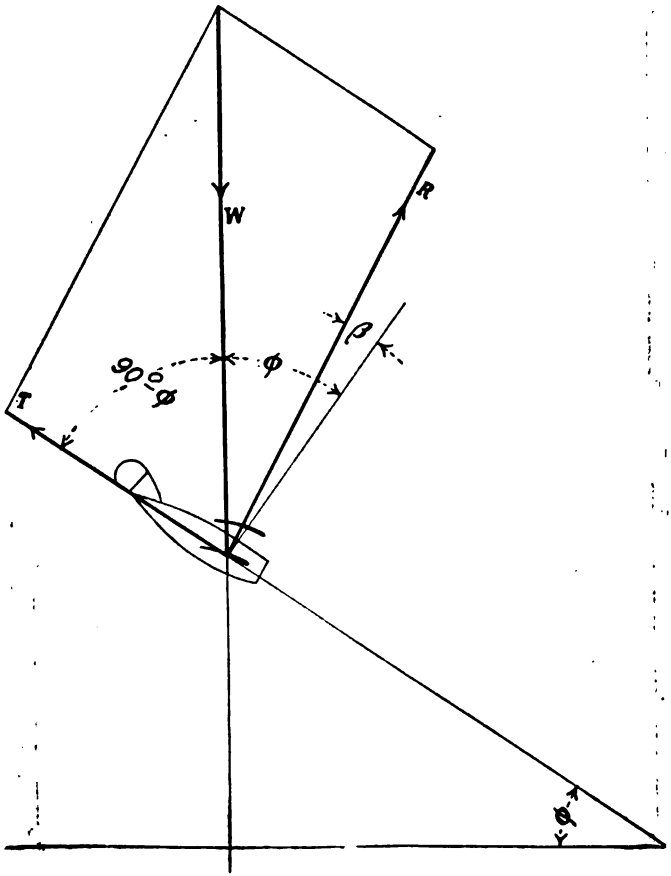

FIG. 11—ANALYSIS OF THE FORCES ACTING ON AN AIRPLANE WHEN GLIDING WITH REVERSE THRUST

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turning at a comparatively slow speed and at relatively high thrust, with the airplane standing still, the pitch of the propeller is considerably lower at top speed when the engine revolutions have increased somewhat, and the thrust has decreased considerably. This feature gives a smaller change in revolution with the engine at full throttle, between the condition at fixed point and the top-speed condition, than is customary with most propellers. For example, most propellers on the Liberty engine show a gain of about 18 per cent between the con-

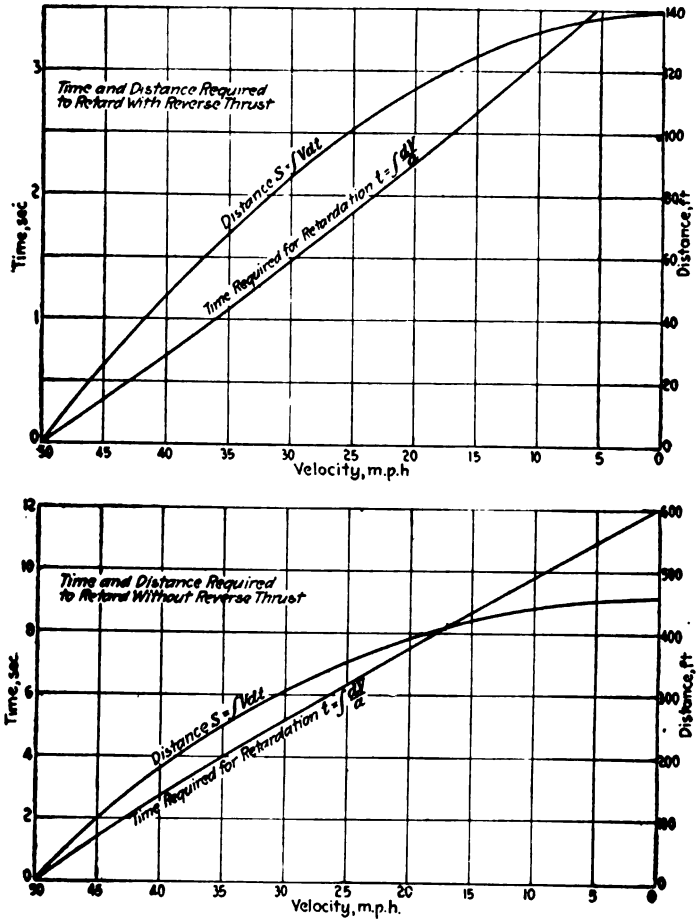

FIG. 12—TIME AND DISTANCE REQUIRED TO RETARD AN AIRPLANE WITH AND WITHOUT REVERSE THRUST

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dition at fixed point and top speed, while the Micarta propeller for this job showed an increase in the number of revolutions of only about 10 per cent. On the USD-9 this propeller showed a slightly better climb and top speed than the wooden propeller for the same job, although turning about 150 revolutions slower at top speed. Thus the radius of action on this plane was greatly improved. A propeller of the same design was used by Major Schroeder in his record-breaking altitude flight. The feature of the increased pitch with an increased number of revolutions and a decrease in the thrust is particu-

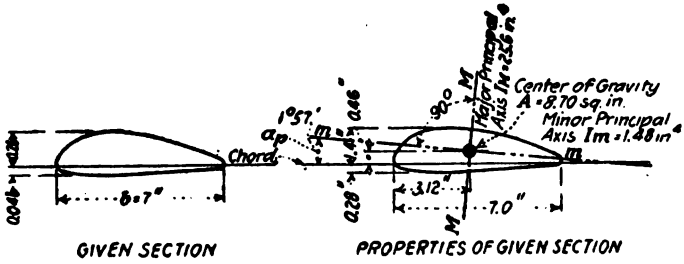

FIG. 13—INSTRUCTION SHEET GIVING THE SECTION PROPERTIES FOR STANDARD AIRFOILS FOR PROPELLERS

It is required to find the properties of a standard airfoil section whose blade width is 7 in. with upper and lower camber ratios of 0.20 and 0.04 respectively. The first step is to find the properties of a similar airfoil with a 10-in blade width, and then by the application of the reduction factors obtain the properties for a 7-in. blade width.

REDUCTION TABLE

Item	Symbol	Value for 10-in. Blade Width	Reduction Factor	Value for 7-in. Blade Width
Blade Width, in.	b	10.00	0.7	7.00
Maximum Upper Camber, in.	h_u	2.00	0.7	1.40
Maximum Lower Camber, in.	h_l	0.40	0.7	0.28
Center of Gravity from Left End Measured along Chord, in.	b_c	4.46	0.7	3.12
Center of Gravity above Chord, in.	h_c	0.66	0.7	0.46
Area, sq. in.	A	17.75	$(0.7)^2$	8.70
Angle between Minor Principal Axis and Chord, deg. min.	a_p	1-57	1.0	1-57
Moment of Inertia about Minor Principal Axis, (in.)⁴	I_m	6.17	$(0.7)^4$	1.48
Moment of Inertia about Major Principal Axis, (in.)⁴	I_M	106.30	$(0.7)^4$	25.60

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larly valuable in connection with the supercharger which was used on this flight, as it gives very simple and direct automatic control of pitch.

The Micarta propellers are extremely durable, being very little affected by grass, sand, small stones, rain, etc. This development appears to have very great possibilities for improvement of propellers.

An enormous amount of research and experimental work has been done throughout the world on steel propellers with little success, as very few, if any, steel propellers are in actual service at the present time. The efforts have been concentrated for the most part along three general lines:

(1) A blade made of two formed sheets welded together along the edges
(2) A blade formed from a tube without welding at the edges except at the tips
(3) Solid steel blade

Under the first classification an interesting development is the Leitner steel propeller designed by H. C. Watts, formerly of the British Air Board. This type of propeller is made up of several sheets of thin material fastened together by riveting, or in some cases by spot welding. The object of the lamination of the material is to avoid harmonic vibration by attaching several pieces having different periods. A number of these propellers are said to have been built for small engines and the builders make large claims for its effectiveness.

The most advanced construction of the tubular type is a reversible propeller built by the Standard Steel Propeller Co. of Pittsburgh. On account of the hollow steel construction it is possible to put all the reversing mechanism on the inside of the blade, giving a very clean appearance to the design. In this case the tubing is swaged down and reamed inside and turned outside to give a thickness tapering toward the tip, as well as a diameter tapering toward the tip. After machining, the tubes are brought to a red heat and pressed to shape in a mold. The material used is a nickel uranium steel which shows some very interesting properties for aircraft purposes.

I designed a solid steel propeller to test out the possibilities of the third type of construction. As was anticipated, this showed a terrific flutter at low speeds on account of the extreme flexibility but ran very smoothly above 1400 r.p.m. The blade stood a remarkable overload test; the cast-steel hub giving way at 2400

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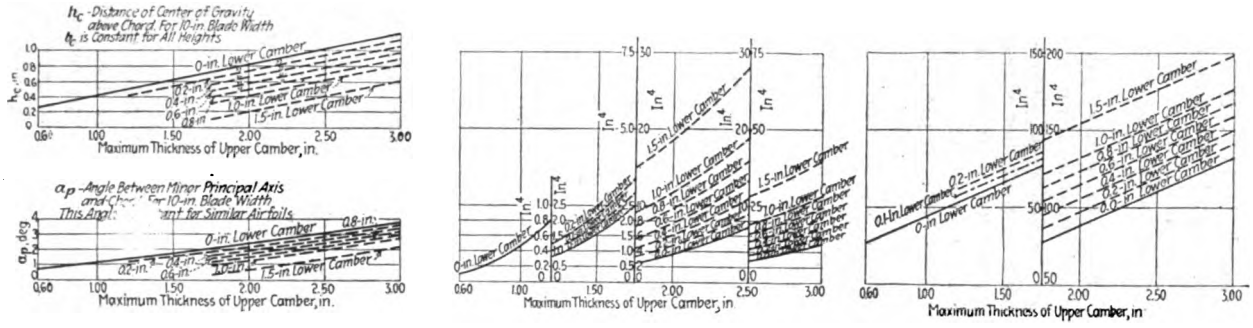

Fig. 14—Charts Giving the Values for the Distance of the Center of Gravity Above the Chord the Angle between the Major Principal Axis and the Chord and the Moments of Inertia About the Minor and Major Principal Axes for a 10-In. Blade Width

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r.p.m. The blade, which is 11½ ft. in diameter, was designed for 200 hp., and at this speed was absorbing about 800 hp. This type of construction appears to have some interesting possibilities, particularly with reversible propellers.

The steel-propeller experiments have demonstrated that the most important consideration in the construction of steel propellers is the degree of flexibility. As is explained under the head of propeller stresses, the centrifugal force always provides a restoring moment in a properly designed flexible propeller. In the design of the steel propeller it is necessary to provide sufficient flexibility to obtain this restoring moment without introducing any very great stresses in the material. At the same time, too great flexibility must be avoided; otherwise the result would be too low a period of oscillation, resulting in violent fluttering of the blades. It is my belief, based on a very wide experience in designing and testing steel propellers, that this feature of flexibility is a most vital one in connection with steel propeller design, and that non-conformity with this requirement has been the cause of most of the failures.

In addition to the above-mentioned steel propellers, the Army Air Service has tested a very large number of interesting designs. Moreover, a great many different types of steel propellers have been tested by the Italians, French, Germans and British. The steel propeller experiments have now reached a point where it seems that something very good will be produced in the near future.

Adjustable-Pitch and Reversible Propellers

Considerable attention has been given adjustable-pitch propellers by experimenters in various countries. A type invented by Professor Reissuer, in Germany, is described briefly in *Technische Berichte,* Vol. III, Section 5. A second type made by Levasseur, in France, has been exhibited at several shows. An adjustable-pitch propeller was produced by the Royal Aircraft Establishment in England. So far as I am aware, none of these propellers is in actual service, and from the information available as to their construction it does not appear that the factor of safety would satisfy our requirements.

It is no secret that the Army Air Service has had considerable success with the Hart adjustable-pitch and reversible propellers, but it is impossible for military

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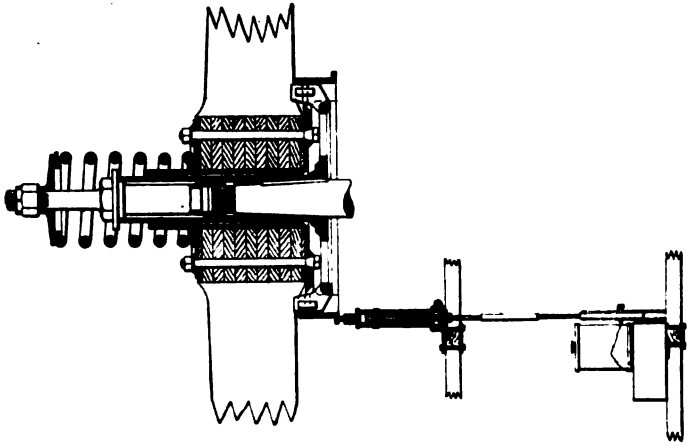

FIG. 15—THRUSTMETER FOR MEASURING THE THRUST IN FLIGHT

reasons to make public any details of its construction at the present time. This propeller was invented by Seth Hart, of Los Angeles, Cal., and several experimental propellers were built at his expense in California, and a number of flight tests were made there by several pilots.

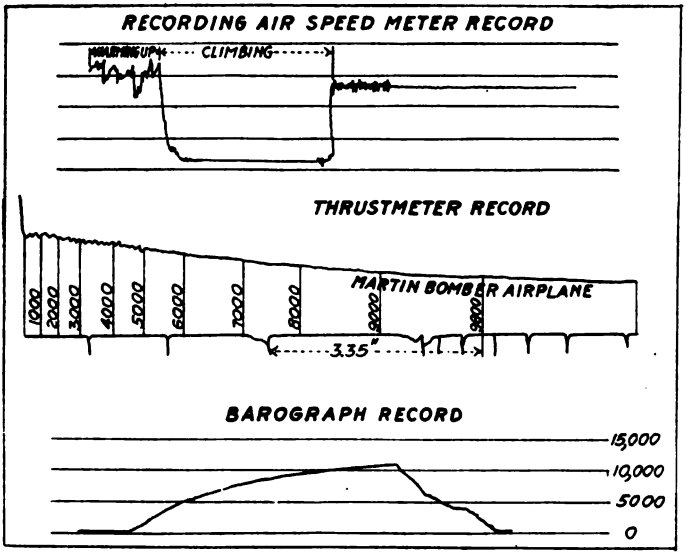

FIG. 16—RECORDS GIVEN BY AN AIR-SPEED METER, THE THRUSTMETER AND A BAROGRAPH OF AN AIRPLANE FLIGHT

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Among the pilots who made the first flights were Earl Dougherty and Lieutenant Mairesse of the French Army. The California flights gave such promise of success that Mr. Hart determined to bring the invention before the Government's Airplane Engineering Department at McCook Field.

The first test given the propeller was a destructive whirling test made to insure its safety for flying purposes. The results of this were so encouraging that the propeller with a few modifications was made ready for flying in a JN-4H airplane. All of the flights with this propeller were made by Caleb Bragg; a very thorough series of tests covering about 8 hr. in the air was made by him. The principal advantages brought out by these tests were that the variable-pitch showed an increase in rate of climb of about 40 per cent as compared with the fixed-pitch propeller, an improvement in ceiling of about 20 per cent and a great gain in the time required for take-off. While it was realized that a considerable length of time would be required to get this propeller ready for production, it was decided to carry on its development as fast as possible without interfering with current production.

The tests have already gone far enough to demonstrate that it is practicable to land an airplane equipped with this propeller on a roof of moderate size and, with some of the modern airplanes, to take-off again. This is possible with existing airplanes designed for military service. With specially designed airplanes the propeller opens the way for a development that should prove of great value to commercial aeronautics. Of course, the first application of adjustable-pitch and reversible propellers ought to be as military and naval equipment. The advantages to the Navy of making possible landings on ships fitted with landing platforms, and to the Army in permitting landings in very small areas, are self evident. Also, the use of the reverse in the air gives the pilot an opportunity for a number of new maneuvers that ought to be very valuable in battle tactics. Reversible propellers in dirigible balloons are well recognized as an aid in maneuvering and in stopping. They are considered essential in ships of very large size. The adjustable-pitch feature of the Hart propollers, which is always combined with the reversible feature, gives a more rapid take-off, a better rate of climb, a higher ceiling, more efficient operation at cruising speed, leading to a

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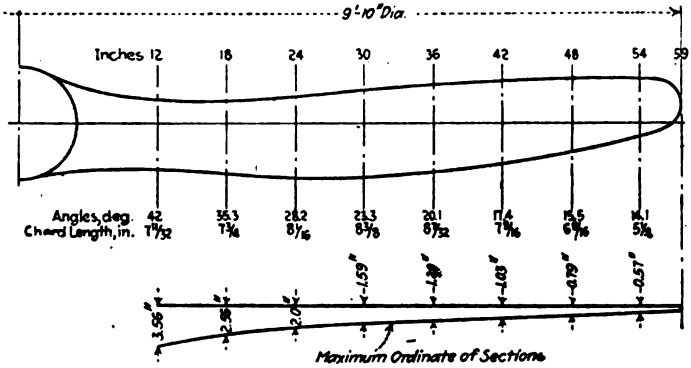

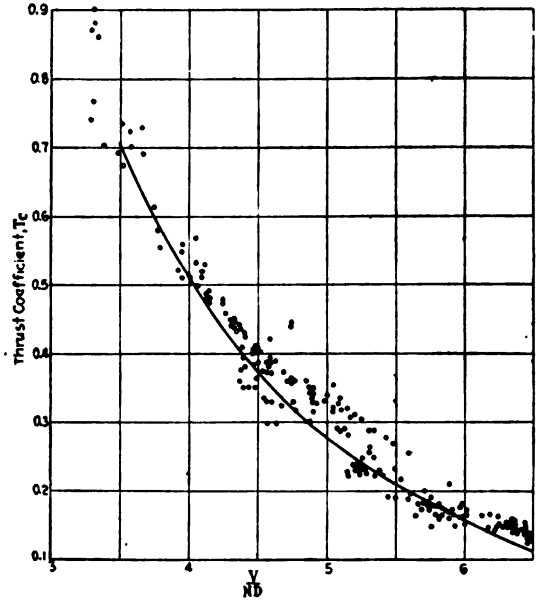

FIG. 17—SECTION ORDINATES FOR A PROPELLER AND UNDERNEATH A COMPARISON OF THE THRUST COEFFICIENTS OBTAINED IN WIND-TUNNEL AND THRUSTMETER TESTS, THE POINTS BEING GIVEN BY THE THRUSTMETER TEST AND THE CURVE BY THE WIND-TUNNEL TEST

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greater radius of action, combined with an efficiency at top speed equal to that of the ordinary wooden propeller.

It has been recognized by all those in different countries experimenting with superchargers that the efficient operation of this device is contingent on the development of an adjustable-pitch propeller. This applies with particular force to equipment designed to operate at heights greater than 20,000 ft. The conventional propeller, if designed to operate at 20,000 ft., will turn altogether too slowly near the ground, and if designed to operate near the ground it will turn altogether too fast at a great altitude. This condition can be met only by the adjustable-pitch propeller, which will permit the engine to operate at a uniform rate at all altitudes. The effect of adjustable pitch on the performance of airplanes with the conventional type of powerplant was described in a paper which I presented before this Society and which was published in THE TRANSACTIONS[4].

I shall not go into the method of computing performance in detail in this paper. In general, there is a great improvement in the time and distance required for leaving the ground when the adjustable-pitch propeller is substituted for the fixed pitch. At the same time an improvement in the rate of climb, ceiling and cruising radius is possible without any sacrifice of top speed. It may be well to call attention to the method of calculating the distance required to stop a plane equipped with reversible propellers. In this discussion the following notation is employed.

R = the parasite resistance at unit velocity
s = the distance covered by the airplane after the propeller is reversed
T = the reverse thrust
t = the number of seconds elapsing after the propeller is reversed
V = the speed of the airplane
W = the weight of the airplane
γ = the value of L/D of the wings corresponding

The retarding forces are

(1) The reverse thrust or T
(2) The wing-drag or W/γ
(3) The parasite resistance or RV^2

The rate of retardation can be computed from the formula $F = Ma$

[4] See TRANSACTIONS, vol. 13, part 2, p. 807.

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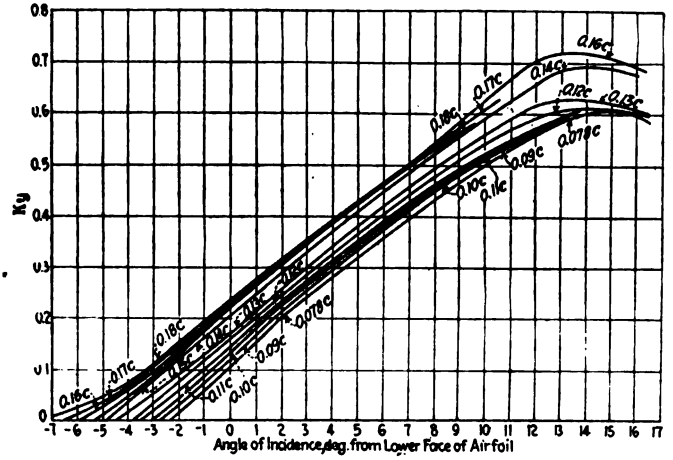

FIG. 18—THE LIFT CHARACTERISTICS OF THE PROPELLER SECTION SHOWN IN FIG. 2

$$\partial^2 s = (gt/W + g/\gamma + gRV^2/W)\partial t^2$$

$$s = \int_0^t \int_0^t (gt/W + g/\gamma + gRV^2/W)\partial t^2$$

This expression gives the distance which the airplane has traveled during a time t after the reverse is applied.

In determining the effect of reverse thrust on the gliding angle

β = the angle between the normal to the path of the airplane and the resultant pressure

$= \tan^{-1} D/L$

$= \cot^{-1} \gamma$

Φ = the angle of descent (See Fig. 11)

Assuming the propeller thrust to be applied parallel to the path

$$W = T \sin \Phi + R (\cos \Phi \cos \beta + \sin \Phi \sin \beta)$$

The following equation connects β, R T and W

$$W = V [T^2 + R^2 - 2RT \cos (90 + \beta)]$$

As an example of the effect of the reverse thrust on the gliding angle, the following can be cited from a practical case. Assume $T = 1000$ lb., $W = 2000$ lb., and $\beta = \tan^{-1} 1/8 = 7$ deg. 7 min. Then the gliding angle ϕ by the above becomes equal to 36 deg. 50 min. Evidently by varying the reverse thrust any desired gliding angle can be obtained. This feature will, of course, prove valuable in entering a confined space but may require much skill in manipulation.

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The forces brought into play in landing are

(1) The parasite resistance of the body
(2) The wing-drag
(3) The friction of the wheels and the tail-skid
(4) The reverse thrust in the case of a reversible propeller

The parasite resistance and wing-drag may be grouped together if we assume the wings to be set at the stalling angle. In this case resistance, parasite and wing-drag will be proportional to the square of the speed. The sum of the two can then be written RV^2.

The coefficient of friction on the wheels can be taken as f and the load on the wheels will be the weight minus

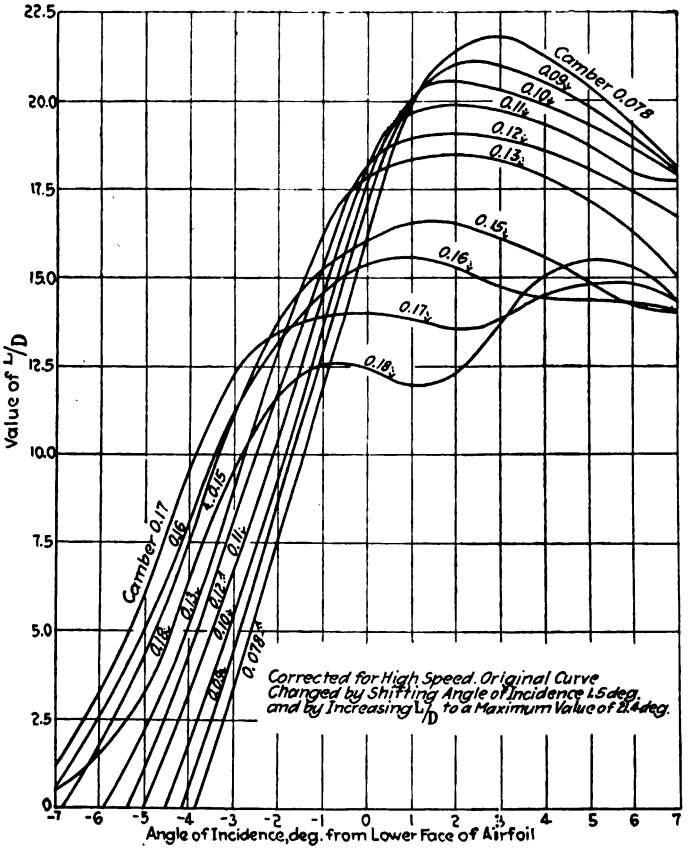

FIG. 19—THE L/D CHARACTERISTICS OF THE PROPELLER SECTION SHOWN IN FIG. 2

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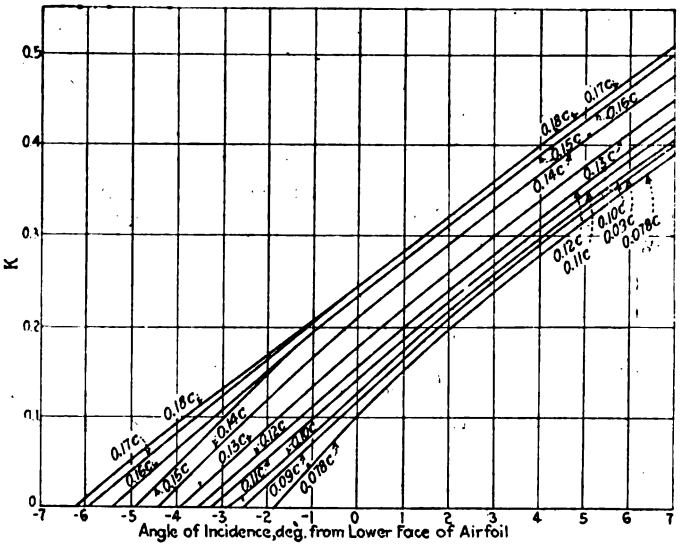

FIG. 20—CURVES GIVING THE TOTAL RESISTANCE COEFFICIENT FOR THE PROPELLER SECTION SHOWN IN FIG. 2

the lift, or $(W - K_y AV^2)$ where K_y is the maximum value. The frictional resistance will be $f\ (W - K_y AV^2)$.

The total retarding force in the case of an airplane without reverse thrust will be

$$RV^2 + f\ (W - K_y AV^2) = W/g \times \text{ the retardation}$$

The formula for the distance required to stop without reverse thrust is

$$s + c_2 = -\ [W/g\,(R - fK_yA)]\ \log \{\ \sec[\,(t + c_1)\,g\,(R - fK_yA)^{1/2}/\ W]\ \}$$

In case reverse thrust is applied, the expression for the distance traveled becomes

$$s = g/W \int_0^t \int_0^t [RV^2 + f(W - K_yAV^2)\ + T]\partial t$$

Since the thrust is variable and cannot be expressed readily in terms of v or t, it is necessary to resort to a graphical method.

The following data can be assumed to constitute an example of landing conditions:

Weight of airplane complete = 2075 lb.

Area of supporting surface = 250.5 sq. ft.

The parasite resistance is equal to 0.01127 V^2

The maximum value of K_y in lb. m.p.h. units = 0.00265

The corresponding value of L/D is 7.5

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The coefficient of friction between the wheels and tail-skid and the earth is 0.2

The corresponding time and distance required to stop are shown in the two sections of Fig. 12.

Propeller Stresses

The question of propeller stresses has received considerable attention during the last few years and the following are well recognized and computed:

(1) The direct tension due to centrifugal force

(2) The bending moments in the thrust and torque plane due to centrifugal force

(3) The bending moments in the thrust and torque plane due to air pressure

In addition to the above, however, very important

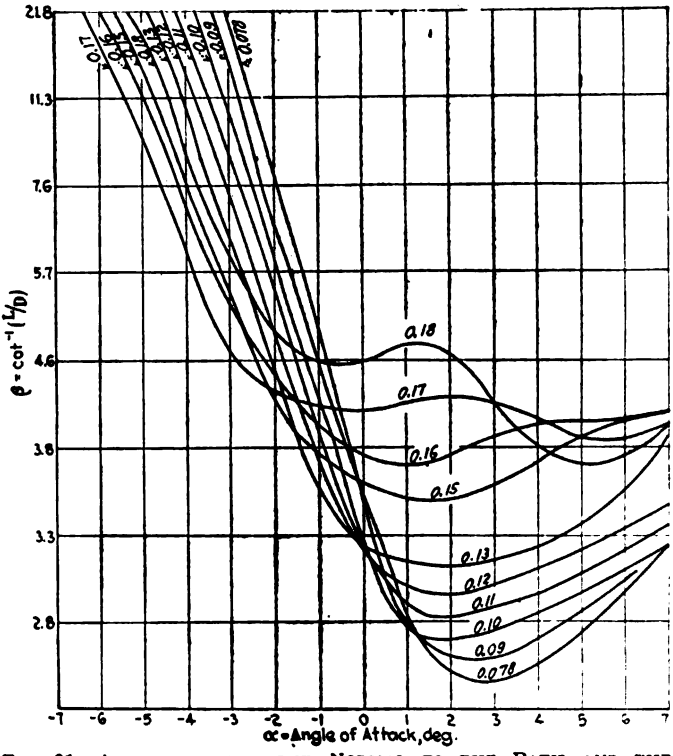

Fig. 21—Angle between the Normal to the Path and the Direction of the Resultant Pressure for Airfoils of Various Thicknesses

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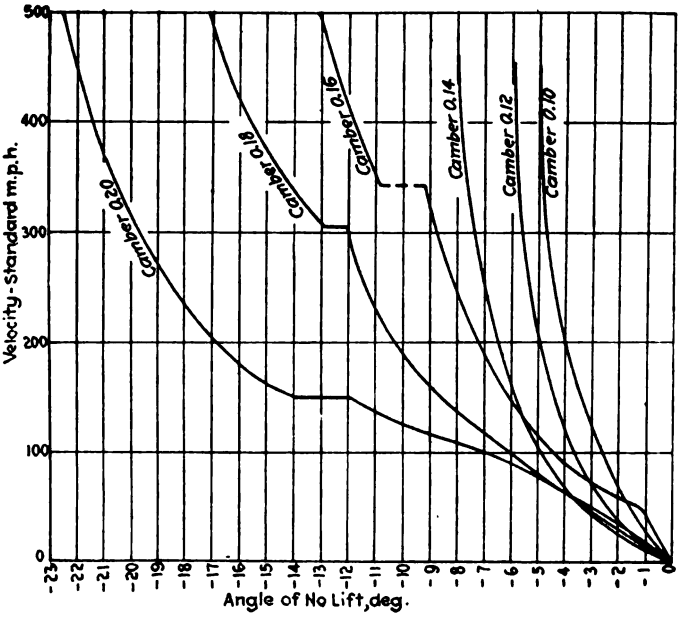

FIG. 22—CURVES SHOWING THE CHANGE IN THE ANGLE OF ZERO LIFT AS THE SPEED INCREASES

stresses are introduced by the torsion due to the air pressure and by the torsion due to the centrifugal force.

In computing stresses it is convenient to start out with the centrifugal force at various stations along the blade. This centrifugal force is computed from the cross-sectional area at the radius of the element under consideration. Applying this formula, the centrifugal force is equal to $1.227\ \Delta\ A\ L\ N^2\ R$, the value of Δ being taken as the density of the material. From these values the centrifugal force acting on each section can be found and, knowing the relative location of the various sections, the bending moments due to centrifugal force can be computed. The thrust and torque are computed from the characteristics of the airfoil sections and the resulting bending moments found.

If the section properties of the various cross-sections of the propeller are known, the stresses can be computed by the usual method of analytical mechanics. The section properties for the series of airfoils referred to in this paper are tabulated in convenient form in Figs. 2, 13 and 14, and can be worked out very rapidly for a pro-

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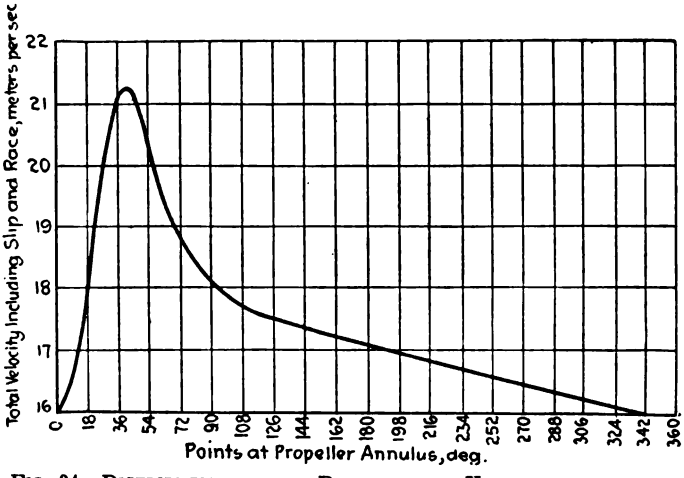

FIG. 24—DISTRIBUTION OF THE PRESSURE AND VELOCITY AROUND THE PROPELLER ANNULUS AT A RADIUS OF 30 CM. (11.81 IN.)

peller section of given camber ratio and width from Fig. 13 by following the instructions given underneath the illustration. For most purposes these section properties will apply to airfoils of somewhat different shape with sufficient precision, provided the camber ratio is known.

In making a static stress analysis of a propeller it should be borne in mind that no action of the deflection of the blade is taken into account. This deflection nearly always results in a considerable reduction of the stress on account of the restoring moments introduced by the centrifugal force. The static stress analysis gives a fairly good comparison of strength values of propellers, provided the shape of the blade is such that it is free from flutter.

PROPELLER TESTING

Propeller tests are usually carried out in four ways: (*a*) flight tests to determine the efficiency and adaptability of the propeller, (*b*) wind-tunnel tests to determine the efficiency and adaptability of the propeller by tests on a small model, (*c*) whirling tests to determine the factor of safety and structural features of full-size propellers and (*d*) tests made on propeller materials and processes of manufacture. Flight tests of propellers have been rather difficult owing to the many sources of error which may reduce the precision and to the lack of suitable instruments. At the present time, however, there are a number of instruments available and under devel-

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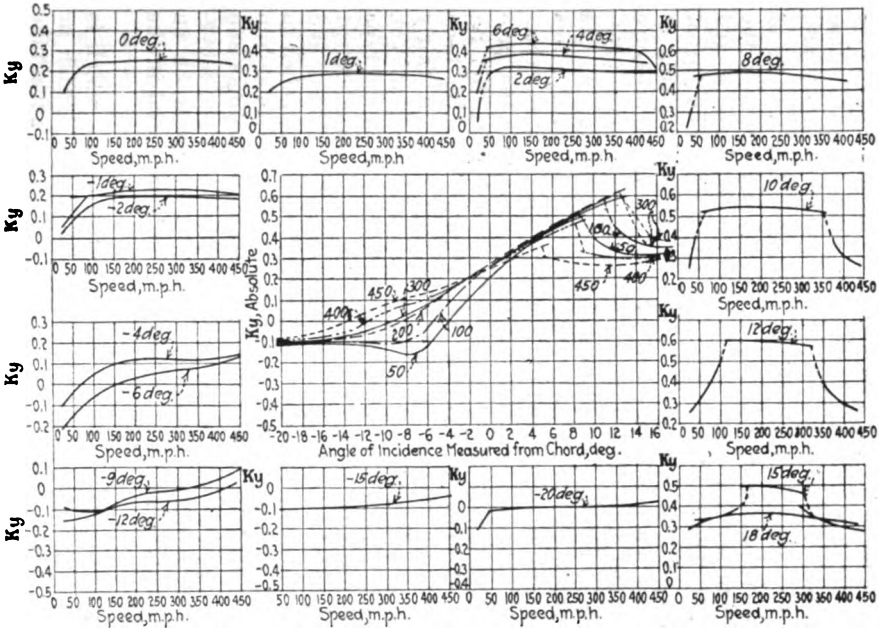

Fig. 23—Curves Showing a Decrease in the Lift Coefficient and a Simultaneous Increase in the Drag Coefficient Where the Type of Air-Flow Changes

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opment which ought to make these tests more satisfactory. In addition to the altimeter, barograph, chronometric tachometer, recording and indicating air-speed meters and thermometers which are used in airplane testing, it is desirable to have thrust and torque meters and a satisfactory means for measuring the slip and race velocities when testing propellers. I shall attempt to give a very brief description of some of these special instruments which have been developed in the last few years.

An instrument which has the very desirable feature of giving simultaneous readings of thrust and torque is the dynamometer hub developed by Dr. Bendemann and tested by the Germans on a Rumpler C-2. The thrust and torque reactions are taken up by pistons working in cylinders filled with oil and the resulting oil pressure is recorded on a drum located in the cockpit. This pressure is led from the cylinders to an extension of the crankshaft and thence through oil-tight grooved rings to a series of tubes leading to the cockpit. It is necessary to carry these tubes all the way around the propeller and the construction is rather clumsy in this respect. It appears that the construction has also been hampered by the lack of first-class material. A fairly complete description of this instrument is given in Vol. III, Section 6, of the *Technische Berichte*. A second type of instrument used by the Royal Aircraft Establishment in England is designed for measuring the thrust and makes use of an external cylindrical bushing attached to the engine shaft-end and, mounted on it, a propeller-hub with a cylindrical bore. This hub is driven by links and is free to move against a calibrated spring. The movement of this hub is traced by a follower roller on an external track and is read from an indicating dial in the cockpit.

Fig. 15 shows a thrustmeter designed by me which is believed to be much sturdier than either the British or German instruments and has the additional advantage that the spring can be calibrated on an ordinary testing machine. One of these instruments has had about 100 hr. in the air, including a flight from Dayton to Washington and return, without any serious wear. There is no appreciable vibration and the pilots do not even remove the instrument when the ship is wanted for cross-country flying. The recording drum in this case is mounted directly on the nose of the engine to avoid any errors caused by the weaving of the airplane structure.

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It is interesting to compare the thrust record shown in Fig. 16 with the air-speed and barograph records of the same flight. During the first 5000 ft. of this climb the air was bumpy or full of whirls. This is shown by the wavy lines in the records of thrust and air speed, and to a somewhat less degree in the barograph record. Above 5000 ft. smoother air was encountered and all three records show a smooth continuous line.

A comparison of the results obtained in the wind-tunnel with the full-scale results obtained from this instrument is interesting. The principal dimensions of the propeller design on which the tests were run are given in the upper part of Fig. 17. The full-scale propeller was 9 ft. 8 in. in diameter, and the wind-tunnel model was 3 ft. in diameter. The wind-tunnel tests were run at Leland Stanford University. A comparison of the thrust coefficients is shown in the lower portion of Fig. 17. The errors in the full-scale thrust coefficient are not thought to be due to lack of precision but rather to the difficulty of synchronizing the readings of the air-speed meter, tachometer, barograph, thermometers and thrust-meter. This emphasizes the desirability of recording all of these readings on the same chart. At the present time three different types of torque meter are being developed for airplane use, and it is anticipated that some very valuable propeller and engine data will be obtained when these are available.

The wind-tunnel tests, being less expensive, have been carried out on a rather comprehensive scale under two main divisions; (*a*) experiments with wing sections suitable for airscrew design and (*b*) tests of models for airscrews. The most valuable work under the former head has been done in England, while comprehensive tests of model screws have been carried out in England, France, Italy, Germany, Russia and the United States. It is impossible to do more than touch on this field of experiment in an article of this kind. A series of sections of British origin, which I have used to some extent with very good results, was shown in Fig. 2. The lift and L/D characteristics of these sections are shown in Figs. 18 and 19. The lift coefficients are the uncorrected values obtained at 30 m.p.h., while the L/D values are corrected for high speed. The same data are shown in Figs. 20 and 21, except that the total resistance coefficient is shown in one curve and the angle whose tangent is D/L is shown in the other. This is more convenient for

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studies of the inflow theory as the mathematics is considerably simplified in this way. I have recently completed some experiments, in conjunction with E. N. Fales, in the high-speed wind-tunnel which we have developed at McCook Field. It has been possible to carry these experiments up to a true air speed of 500 m.p.h. on account of the exceptionally uniform traverse of the air-flow in this tunnel and some new features of propeller airfoils have been brought to light. Of particular interest is the change of the angle of zero lift as the speed of the air increases. In Fig. 22 it will be seen that the angle of the chord at zero lift changes very slightly for thin airfoils, such as used in airplane wings, while the change in thick sections, such as are sometimes used in propellers, is enormous. Of further interest has been the visualization of the air-flow, of which numerous photographs have been obtained. In all of the airfoils tested we encountered, at high speeds, a critical velocity where the type of air-flow changes, the lift coefficient showing a sudden decrease and the drag coefficient a simultaneous increase as illustrated in Fig. 23. It is interesting to see the change in the air-flow at this critical speed as the flow changes in the same way for all the models.

One cannot give too much praise to the extremely careful and conscientious airfoil work done at the National Physical Laboratory in England. This work has formed the ground-work for much of the experimental work in propellers. Many valuable airfoil data have also been furnished by Eiffel, Costanzi, Prandtl and numerous other experimenters. Dr. Durand's monumental series of propeller tests is now so well known as to need no description. In addition to the published tests, many models of Air Service propellers have been tested at the Leland Stanford University through the cooperation of Dr. Durand and Professor Leslie. Of special interest among recent-model propeller tests is the series of tests of Eiffel with tandem propellers. M. Eiffel has shown that it is possible to have a tandem arrangement with very high-pitch propellers rotating in opposite directions, where the combination shows a higher efficiency than either propeller running alone owing to the absence of race rotation in a properly designed tandem combination. M. Drzwiecki has published the results of an extraordinarily interesting series of experiments wherein he obtained the instantaneous velocity distribution throughout an annulus of the propeller disc, and has shown the

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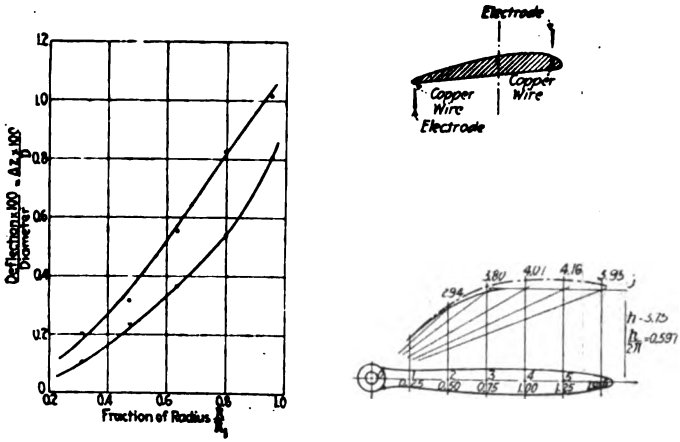

FIG. 25—AT THE LEFT DEFLECTIONS OBTAINED IN A WHIRLING TEST ON A GERMAN PROPELLER AND IN THE UPPER RIGHT CORNER THE METHOD OF MEASURING THE DEFLECTIONS BY ELECTRIC CONTACTS WITH THE CHANGE OF PROPELLER PITCH RESULTING FROM THESE TESTS UNDERNEATH

presence of a circulation about the propeller blade analogous to that known to exist about airplane wings. It appears that this series of experiments will make necessary a modification of the inflow theory which has become fairly well established during the last few years (See Fig. 24).

The facilities for making whirling tests of practical propeller designs, construction and materials have been fairly well developed in England, Germany and the United States; but, as far as I know, the French and Italians still depend on static tests. I am told that the French Section Technique was unable to obtain facilities of this kind during the war, owing to the scarcity of electrical machinery in France. The European whirling stands are all comparatively small; the largest so far as I know being capable of developing about 600 hp. The British have about three of these stands and make a very large number of tests. The Germans have a whirling stand for testing. In testing they have studied deflections in much the same way as we have studied them at McCook Field, taking the deflection of the leading and trailing edges and computing the change in angle. The upper view in Fig. 25 shows the test described by H. Dietzius in Vol. III, Section 2 of the *Technische Berichte.* The deflection measurements are obtained by means of

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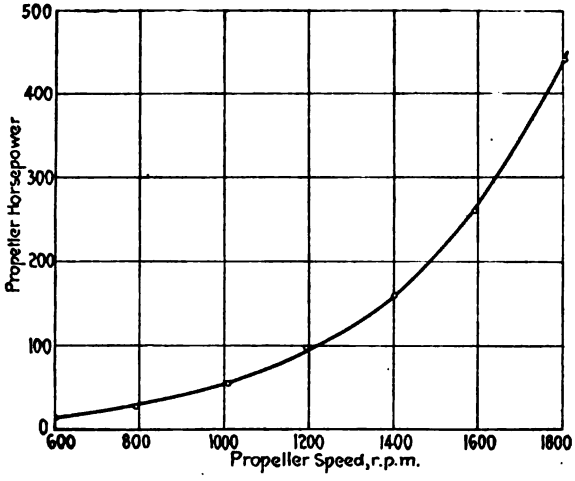

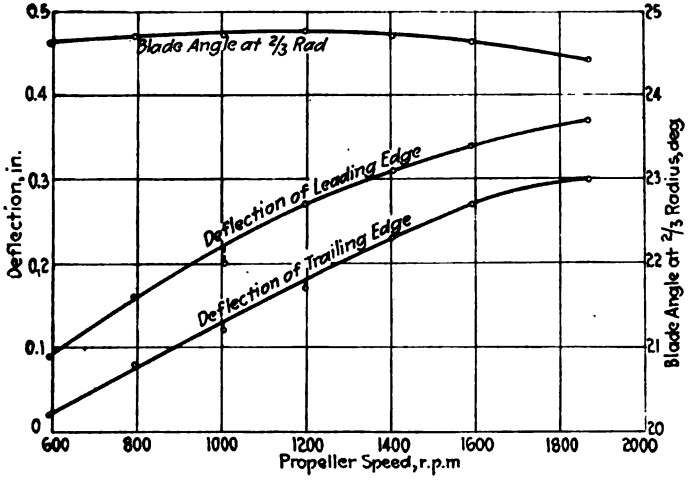

FIG. 26—PART OF A TYPICAL SET OF READINGS FROM A PROPELLER TEST MADE AT MCCOOK FIELD

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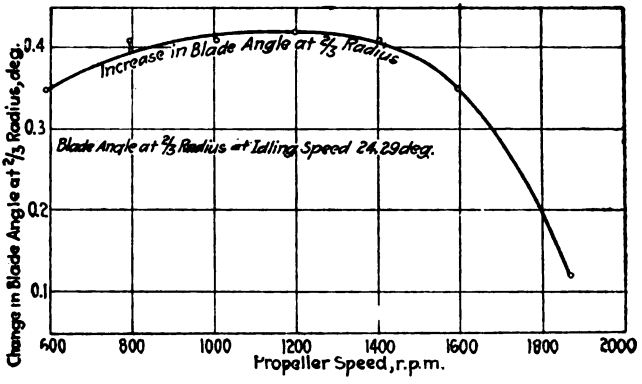

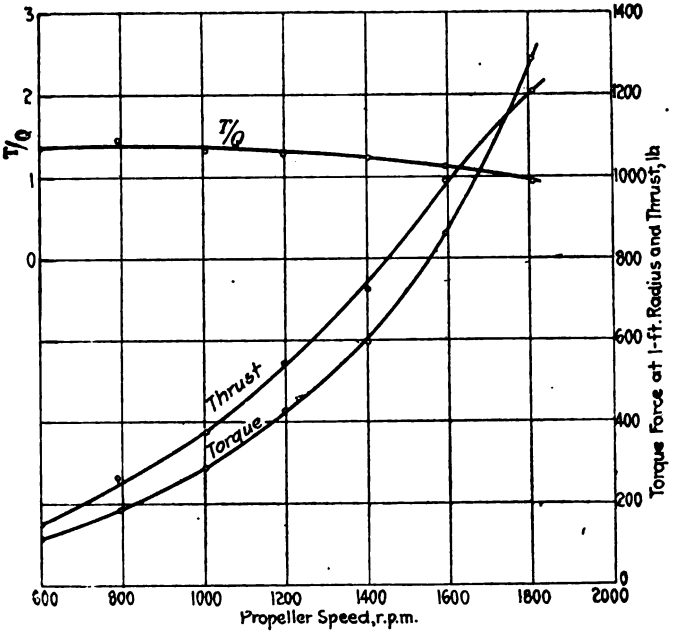

FIG. 27—REMAINDER OF THE RESULTS OF A PROPELLER TEST MADE AT McCOOK FIELD

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electric contacts, but the exact method is not clearly described in this article. The results are typically the same as those observed in our propeller work, a greater deflection being noted on the leading edge, resulting in an increase of pitch.

The propeller-testing laboratory of the Air Service at McCook Field has a capacity of 1400 hp. for a short time, and is equipped with a bombproof and a special device, so that the propeller can be completely destroyed in testing without throwing any unbalanced load on the driving-shaft. The usual practice in making a test on a propeller at McCook Field is to obtain readings of the torque, thrust and speed, the deflections and change of pitch, at various speeds up to 50 per cent above the rated horsepower of the engine. This test is usually followed by a run at 50 per cent above the rated horsepower of the engine. It has been found that this test gives a satisfactory factor of safety for wooden propellers. For propellers of other materials, special tests are carried out according to requirements of the material. The readings of thrust are obtained directly from the Toledo scale, and the readings of torque are taken both electrically and mechanically. The deflections are read by a telescope with cross-hairs which is adjusted until it lies in the plane of revolution of the leading and trailing edges respectively. A typical set of readings from one of these propeller tests is shown in Figs. 26 and 27.

A water-spray test also is arranged, and tests of the resistance to abrasion are run from time to time. One of the most complete tests carried through consisted of a 200-hr. run on a Micarta propeller designed for the Liberty Engine.

Tests of propeller material are of considerable importance, the quality of wood being usually determined by the specific gravity rather than by a strength test, owing to the great variation in results of strength tests, according to the method by which they are made, and depending upon the manner in which they are carried out. The specific-gravity test is very positive and appears to give a very clear indication of the quality of material. The most elaborate series of tests of wood with which the writer is familiar is that made by Mr. Newlin, of the Forest Products Laboratory. I have compiled some of the properties of a number of propeller woods, together with those of annealed steel and Micarta; these are given in Table 1.

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TABLE 1—ACTUAL AND COMPARATIVE PROPERTIES OF VARIOUS WOODS AND OTHER AIRPLANE PROPELLER MATERIALS

Common and Botanical Name	Specific Gravity at 15 per cent Moisture Including Water	Shrinkage from Green to Oven-Dry Condition		Strength in Bending	Strength in Compres'n Parallel to Grain	Strength in Compres'n Perpend'l'r to Grain	Stiffness	Hardness	Shock Resisting Ability, lb.	Shearing Strength Parallel to Grain. lb per sq in.
		Radial, per cent	Tangential, per cent	Modulus of Rupture, per cent	Maximum Crushing Strength, lb. per sq. in.	Fiber Stress Elastic Limit, lb. per sq. in.	Modulus of Elasticity in Bending, lb. per sq. in.	Load Required to Imbed a 0 44-in. Ball for One-Half its Diameter, lb. per sq. in.		
Birch, yellow (Betula lutes)	0.63	6.9	8.9	13,200	7,040	803	1,800,000	980	19.0	1,622
Cherry, black (Prunus serotina)	0.54	3.7	7.1	12,030	7,080	777	1,632,000	883	12.8	1,990
Spruce, Sitka (Picea sitchensis)	0.39	4.5	7.4	8,240	5,200	570	1,480,000	490	6.4	1,165
Maple, Oregon (Acer Macrophyllum)	0.51	3.7	7.1	11,080	6,480	970	1,370,000	830	8.7	1,660
Oak, white (Quercus alba)	0.68	6.2	8.3	12,120	7,000	1,450	1,420,000	1,310	12.1	1,790
Walnut, black (Juglans nigra)	0.59	5.2	7.1	14,230	8,600	1,051	1,770,000	1,195	14.6	1,822
Poplar, yellow (Liriodendron tulipifera)	0.42	4.1	6.9	8,350	5,100	542	1,570,000	450	5.6	1,180
Micarta	1.35	...	...	20,000	30,000	....	500,000	.....	....	2,000
Mild Carbon Steel (Soft)	7.84	...	...	60,000	.....	....	29,000,000	.....	....	.....
Alloy Steel (Heat-Treated)	7.84	...	...	100,000	.....	....	30,000,000	.....	....	.....

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THE DISCUSSION

PROF. E. P. WARNER:—Mr. Caldwell's paper is of peculiar interest at present because, after having been in a state of constant change and improvement for a number of years, propeller design seems now to be arriving at something like finality. It appears probable, from the work that has been done at Dayton, elsewhere in this country and abroad, that it will be possible within a short time to predict accurately the characteristics of a propeller from nothing more than a knowledge of the sections employed in the making up of that propeller.

As to what is being done abroad, in addition to experiments with the thrust-meter that they are working with, the British are obtaining the pressure distribution on a propeller in flight as well as in the wind-tunnel, to provide data for the application of the new-type propeller-theory to design. The Royal Aircraft Establishment is actually obtaining in flight now the pressure on 105 points of the propeller, and they can build up the thrust and the torque from these pressure plottings. In the matter of strength testing that Mr. Caldwell mentions, the European method is different. The most striking difference to me, after seeing what they are doing in England, is that they attempt to catch the propeller without serious injury, in going against boards or concrete. For that purpose the propeller is surrounded, in both British and German laboratories, with wire fence of an exceptionally springy weave. It has a springy mesh with the idea that, when a part of a blade lets go, it will strike the wire and rebound, be less injured and be easier to examine afterward than if it goes against a concrete wall. They seem to have good success, although they do not test to destruction, as a rule. Usually, they run the propeller up to 25-per cent overload and, if it stands up, do not attempt to break it.

They are working in England with a propeller made up of an aluminum frame having sheet aluminum screwed on both sides as a cover. That was not tried in flight last summer but tests on it were reported to show very good results. It gives a better form than most of the steel propellers that they have had. It is a promising rival to the steel propeller, if wood is finally abandoned on account of its poor resistance to climatic conditions and its poor durability.

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A SUGGESTED RULE FOR RATING RACING CARS

By H M Crane[1]

In recent years automobile engines for racing purposes have been very generally rated in accordance with their piston displacement. The natural result has been to encourage the highest possible engine speeds to attain the greatest possible piston displacement per minute. Features of engine design that have been developed under this rule include enormous valve areas, usually obtained by a multiplicity of valves, huge inlet pipes and carbureters, extreme valve-timing and very light reciprocating parts, all of which are undesirable in commercial engines.

To encourage the design of engines of a type developing higher efficiency at lower engine speeds, the suggestion is made that a rule be formulated under which cars will be rated in accordance with the piston displacement per mile actually used by them. Such a rule would involve rear-wheel diameter and gear-ratio, as well as the piston displacement of the engine. This would automatically allow the use of engines of varying size, provided the other elements were proportioned properly.

In recent years automobile engines have been very generally rated for racing purposes in accordance with their piston displacement. The rule in most general use last year placed a limit of 183 cu. in. on this feaure. The natural result of this method of rating has been to encourage the highest possible engine speeds with the object of obtaining the greatest possible piston displacement per minute. There is plainly no limit to the power that can be attained in this way, except that imposed by the great loss in mechanical efficiency at very high speeds and the increasing difficulty of maintaining a reasonable volumetric efficiency at such speeds. Much has been learned regarding the design of high-speed engines from the work done under this rating rule, but I think the time has come when we can expect to get very little more of value from a continuance of it for purposes of the commercial design of passenger cars and trucks.

Most automotive engineers are familiar with the features of engine design that have been developed under

[1] M.S.A.E.—Consulting engineer, New York City.

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this rule. We find enormous valve areas, usually obtained by a multiplicity of valves; huge inlet pipes and carbureters, extreme valve-timing and very light reciprocating parts. However desirable these features may be for racing purposes, all experience indicates that they are highly undesirable in commercial engines. Those first mentioned make good performance at moderate and low engine speeds absolutely impossible with the present type of fuel, while the very light pistons used cannot be expected to give either reasonable wear or proper control of lubrication in commercial service.

I doubt whether it would be possible to formulate any rating rule that would tend to develop a really commercial type of engine for racing purposes, but I believe that it should be possible to do something to encourage engines of a type developing higher efficiency at lower speeds than is now the case. My suggestion is the development of a rule under which cars will be rated in accordance with the piston displacement per mile actually used by them. Such a rule would involve rear-wheel diameter and gear-ratio, as well as the piston displacement of the engine. This would automatically allow the use of engines of varying size provided the other elements were properly proportioned. The use of gearboxes in most racing cars would perhaps make the application of such a rule difficult if not impossible in the case of road races in hilly country. In the case of track races or races on the flat, such a rule should be readily enforceable.

I am bringing forward this suggestion in the hope that it will induce automotive engineers to think along these lines. Racing is very expensive and I think the matter of getting more information of real engineering value out of it, if possible, is worthy of the most serious consideration.

THE DISCUSSION

CHAIRMAN H. M. CRANE:—My paper entitled A Suggested Rule for Rating Racing Cars, states all that I have to say on this subject. I hope the engineers in the automotive industry will do some thinking along those lines, for I believe they might in this way learn more by racing than they are apt to learn under the present rule.

This meeting was called primarily to bring out questions that have come up in our various conferences on fuel with the members of the petroleum industry. We have been under a constant fire from the other side,

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on the question of why we use so much gasoline. When I first began using gasoline, about 1898, the producers did not worry about how much we used; in fact, they worried about how little we used. However, they have put a strong burden of proof on the engineers in this industry to show why we should not reduce our consumption per passenger-mile and per ton-mile. The greatest and most spectacular gains in this direction can be made in engine design and in a most interesting line of work. On the other hand, we must not overlook the fact that those gains are simply in the production of power, and that we must show also that we are not using more power to accomplish results than is justified.

The petroleum industry has taken a certain point of view regarding the use of the small car, that I think deserves comment. The automobile is supplied to give service; if it is a truck, it must carry tonnage; if it is a passenger car, it must carry passengers. Part of the service in carrying passengers lies in the speed at which the passenger cars are operated and the comfort in which the passengers are transported. We have no right to overlook these facts. We are called upon to give the public comfort and speedy transportation, even if this uses somewhat more gasoline than slower or less comfortable transportation. For instance, I think we cannot ask the public to use open cars without tops or windshields, simply because they require less gasoline to drive than sedans or limousines. In that case, we would not be giving service to the public.

I will speak of several points regarding chassis design to illustrate what I have in mind regarding the possibilities in that direction. We have been asked by the petroleum industry why we use such high-geared cars; why the public is given cars that can go everywhere, almost, on high gear. The public does want such cars, but is it not for the reason that gearshifting today is largely a matter of strengh and acrobatics? We have made gearshifting so difficult that the use of the lower gears is confined to starting and times when progress cannot be made in any other way. Unfortunately, the design of the present type of engine is such that the very means we use to cut down its power, throttling, also reduces its economy. I was told of some very interesting tests that had been made to illustrate this fact. On a flat track a car would make the best mileage per gallon if opened up wide for a given distance, accelerated to a fairly high

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speed and then allowed to coast for a given distance with the engine shut off. That is a very clear illustration of what I mean. Theoretically, that should not be the case so far as the resistance of the car is concerned, because the resistance of a car to propulsion is not in the form of a straight-line curve, but goes up very rapidly with increase of speed; and, the higher the speed is, the more rapidly it goes up.

Another phase in which many of our smaller cars are deficient is the braking. The brakes are partially applied all the time, and no reasonable means is provided for the average owner to keep them properly adjusted so as to hold when he wants them to hold and yet not drag when that is not desired. Another feature, common in some of the cheaper cars, is the defects of gearbox and rear-axle design. These gearboxes and axles are designed in such a way that oil cannot be used for lubrication. Grease of a heavy character is required, for oil will escape so rapidly that the gearboxes rapidly become dry and the cost of operation with oil too great. In high-speed apparatus, such as the automobile rear-axle and gearbox, grease is a very poor lubricant. It also absorbs a large amount of power in operation. In other words, many probably had experience in the old days with cars whose gears could not be shifted on a cold morning and yet after running for a time could be shifted easily. That was partly due to the heat of the engine but, also because the churning of the grease produced heat and power was required to produce it.

I have sketched a few points that enter into the big problem of economy of service. I say "service," as against economy of operation, because economy of operation only goes part way. We must give the owner service and at the cheapest price. Part of the service, as I said, is in speed and comfort.

I am glad that Mr. Putnam put so much emphasis on the tire question. The tire companies have failed in their literature to begin to take advantage of the possibilities of the cord tire. They have recommended pressures that produce exactly the results Mr. Putnam has outlined. For obvious reasons the cord tire is a big improvement over the fabric tire in efficiency. The efficiency of any spring is the amount of energy that it will return, compared with the amount put into it. The fabric tire is inherently a shock-absorber, and that is the cause of its relatively great self-destruction; being a shock-

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absorber, it absorbs energy and over-heats. The difficulties that Mr. Putnam outlined come from very plain causes. In the rear-axle, especially, we have a heavy weight swung between two sets of springs and, unless it is damped in some way, it will acquire, under certain conditions, some very remarkable activities when the periods of the two sets of springs get into certain relation.

AUSTIN M. WOLF:—Mr. Crane's suggested rating rule for racing cars is a very meritorious one and it should result in increasing the efficiency of the car as a whole, in that everything else will be taken into consideration and receive as much attention as the engine receives today. We picture engines and nothing else when we think of racing cars, and neglect to a large extent the rest of the chassis. Limiting a car to a certain piston displacement will develop an engine that is good for only high and constant speed. This, as Mr. Crane says, is not the commercial engine we desire for automobile use.

I think that Mr. Crane's suggestion can be applied to advantage in our present-day production of cars, carrying the displacement to a weight basis, and while the figures I give are susceptible of various interpretations, they nevertheless bring out some interesting facts. What I propose to do is to consider the piston displacement per mile per pound of total weight of the loaded car and per pound of passenger-weight. I have divided the cubic inches of piston displacement per mile by two, in that the result would be the amount of charge that the four-cycle engine would draw in through the carbureter. The relative value of the figures remains the same nevertheless, and this figure could be used in determining the theoretical fuel consumption on a basis of air to fuel ratio.

Table 1 lists representative touring cars and also a motorcycle with a side-car. A summary is given of the cylinder size, the piston displacement in cubic inches, the tire size, the revolutions of the tire per mile, the gear-ratio, the cubic inches per mile inspired through the carbureter, the weight of the car ready for the road with complete equipment and the tanks full, the number of passengers, the total weight, the percentage of the passenger to the total weight, the cubic inches per mile per pound of total weight, and the cubic inches per mile per pound of passenger-weight.

It is interesting to note that, on a basis of total weight,

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the motorcycle consumes a greater number of cubic inches than any of the cars. However, due to the fact that the passenger load constitutes 35 per cent of the total weight, we find that the motorcycle obtains the best performance on a basis of cubic inches per pound of passenger-weight. This is an argument for reducing the weight of our cars. As Table 1 shows, the passenger load constitutes from 18 to 22 per cent of the total load.

The effect on the gear-ratio is very noticeable in the case of Car E. For its size this car consumes the smallest number of cubic inches per pound of total weight of any of the vehicles mentioned, and in the cubic inches per pound of passenger-weight it shows a very creditable figure. The table is, of course, based on the rated capacity of the manufacturer. Referring to Car E, there is no doubt that a seven-passenger model could be built that would weigh the same as the six-passenger type. In this event the cubic inches per pound of total weight would be 71.67, and the cubic inches per mile per pound of passenger-weight 346.75, which is the best figure of any under Column 12. The effect of a high gear-ratio is thus brought out, in line with the findings of Mr. Nelson in his paper on the Fuel Problem in Relation to Engineering Viewpoint.[6] The figures in Table 1 assume, of course, that the efficiency of the carbureter, engine, transmission, axle, tires and the like, is equal in all cases and that all losses are the same. This, however, is not the case and probably a factor which is the readiest criterion would be the miles per gallon of fuel consumed. There still would be some variables such as atmospheric conditions, road and wind resistance and kind of fuel. If we divide the figure that is obtained in Column 12 by the number of miles per gallon, we obtain another result that is very interesting. We assume that the vehicle obtains the number of miles per gallon of fuel given in Column 13. The results in Column 14 show what light-weight construction can do, as in the case of a motorcycle.

W. P. KENNEDY:—I am presenting this communication on behalf of Col. A. J. Slade, who was in Europe during the war period as chief of the engineering division of the Motor Transport Corps and, as a member of the International Armistice Commission, went into Germany to take over the German trucks. He was impressed while over there with the desirability of using light cars for courier service and, in collecting the German trucks, took

[6] See p. 325.

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TABLE 1—PISTON DISPLACEMENT PER MILE PER POUND OF TOTAL CAR-WEIGHT AND PER POUND OF PASSENGER-WEIGHT

Column			1		2	3	4	5	6	7	8	9	10	11	12	13	14
Designation	Car: Type	Car: No. of Cylinders	Bore, in.	Stroke, in.	Piston Displacement, cu. in.	Tire Size, in.	Tire Revolutions per Mile	Gear-Ratio on Direct Drive	Fuel Inspired, cu. in. per mile	Weight with Complete Equipment, Tanks Full, lb.	Number of Passengers	Total Weight with 150-lb. Passengers, lb.	Percentage of Passenger to Total Weight	Cubic Inches per Mile per Pound of Total Weight	Cubic Inches per Mile per Pound of Passenger-Weight	Assumed Mileage per Gallon	Col. 12 Divided by Col. 13
A	Ordinary	12	3	5	424.1	35	576.2	4.36 to 1	532,720	4,746	7	5,796	18.1	91.91	507.35	....	.....
B	Ordinary	8	3⅛	5⅛	314.4	35	576.2	5.07 to 1	459,324	4,035	7	5,085	20.6	90.33	437.45	10.0	43.74
C	Large	6	3½	5¼	303.1	33	611.2	4.33 to 1	401,385	3,690	7	4,740	22.2	84.68	382.27	....	.....
D	Small	6	3⅛	4¼	195.6	33	611.2	4.63 to 1	277,149	2,600	5	3,350	22.4	82.73	369.53	....	.....
E	Large	4	3¾	6¾	298.2	32	630.2	3.87 to 1	364,098	4,030	6	4,930	18.2	73.85	404.55	12.5	32.36
F	Small	4	3¼	5½	182.5	32	630.2	4.87 to 1	280,344	2,640	5	3,390	22.1	82.70	373.79	20.0	18.69
G	Motorcycle with Side-Car	2	3 5/16	3½	60.3	28	720.3	4.91 to 1	106,701	563	2	863	34.8	123.64	355.67	35.0	10.16

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advantage of this opportunity to send back three models of very light car which had been used by the Germans in courier service and which have since been in Baltimore. He recently communicated with the Engineering Section at the Motor Transport Depot, Camp Holabird, Baltimore, Md., asking what disposition had been made of these three machines and whether any progress was being made in taking advantage of them in the camps, in applying them to military service. The communication from W. T. Norton, chief of the engineering branch, Motor Transport Corps, is as follows:

> Relative to small German passenger cars, this section has at present three such cars; namely, a Mathias, a Benz and a Wanderer. The Wanderer car has been rebuilt and is in courier service between Camp Holabird, Md., and Washington, averaging 110 miles per day. The Mathias car is being rebuilt and probably will be put in the same service in the near future.
>
> The general idea of testing out these cars is to see if there is any possibility of doing away with the heavy motorcycle and side-car which has been used previously for mail courier service. The maintenance of the heavy motorcycle and side-car in this kind of service is excessive and the tests which we have conducted so far indicate that a car of the Wanderer type will be more economical to maintain and more reliable.
>
> In the event that cars of the Wanderer and the Mathias types test out successfully, it is believed that these vehicles should be Americanized. The track should be increased from 48 to 55 or 56 in. and the general design changed to make the various units more accessible. The present German designs are such that repair work on any of the units is very difficult, requiring considerable time and labor.

JOHN YOUNGER:—I did a good deal of work on splined shafts from 1913 to 1915 and embodied the results in a paper presented before the American Society of Mechanical Engineers.[3] This paper shows the effects of different heat-treatments on splined shafts, the effects of several alloy steels and also the effects of various diameters on the central portion of the shaft. I think it proves conclusively, as does Mr. Spicer, that the strength of the shaft with splined ends is the same as the calculated strength of the smallest diameter at the bottom of the spline. Reference is given in my paper, in connection

[3] See *Transactions of the American Society of Mechanical Engineers*, vol. 39, p. 355.

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with some of the tables, to part of C. E. Garrard's study of splined shafts made several years before. It seems to me that a bibliographical list of such papers should be compiled.

C. W. SPICER:—Attention should be called to the fact that the experiments reported on in my paper indicate that the strength of a splined shaft is even *less than* the strength of a full-round shaft of diameter equal to the smallest diameter of the spline. To be specific, the difference in this particular case amounts to an average of 18 per cent. This discrepancy is of sufficient importance to be taken into consideration when making careful calculations.

CHAIRMAN CRANE:—I do not know whether Mr. Spicer has had an opportunity to go into the effect of repeated stress on splined shafts, but the tendency is distinctly to enhance the effect he has found on a straight torsional test, especially if the fillets in the corners of the splines are not amply great. We had a shaft break in torsion under those conditions. It looked like a perfectly good pie cut into segments, with cracks leading from the center to the corners of the splines. Of course, what happened was that the metal of the spline actually aided in overloading the already highly stressed metal on the surface of the round part of the shaft. I hope that, if Mr. Spicer has made equivalent tests on various sizes of squared shaft, he will give us the benefit of them at this or at some later date.

PROF. S. E. SLOCUM:—The main object of the type of suspension described in my paper is to relieve the chassis from the vibration ordinarily transmitted to it by the engine. It is not necessary, in this connection, to discuss what produces vibration of the engine, but only to consider the effect of vibration on the chassis. Whenever the speed of the engine falls into step with the natural frequency of vibration of the chassis or of the body, the vibration is greatly intensified; in other words, whenever we have synchronism between the engine and the chassis we have those excessive vibrations known as periods. If it were not for this synchronism between the engine and the chassis, the average person would scarcely know there is any such thing as vibration. Therefore, relieving the chassis of vibration is very largely a question of destroying synchronism between the engine and the chassis.

MR. WOLF:—Will Professor Slocum state why the rigid support of the suspension system he described is located

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under the transmission? Is there any particular reason?

PROFESSOR SLOCUM:—The idea is to minimize motion of the brake-lever or the gearshifting lever, but the whole suspension can be reversed just as well, and the fixed point placed in front and the springs in the rear; or any other combination that seems best for a particular engine is feasible. The thing is to adapt the principle to the engines as they are at present. The most practical, although not the ideal, way seems to be to mount them in a cradle as shown.

JOHN G. PERRIN:—I cannot say that we have much to learn from what I saw recently in Europe. We have heard much about the wonderful economy obtained there but, although perhaps we might find some modifications in the engines or cars, my conclusion is that there is nothing radical in that respect. They obtain the high economies we hear about with small cars, such as would not be adapted to use in this country unless we got over the idea of wanting to do everything on high-gear. The so-called small cars have about a 48-in. track. We found that absolutely unsuitable to American conditions, except in sections where the roads were very highly improved. The engines are practically not different from ours. They are using a great number of I-head engines, but there is still a greater number of L-head engines. They are improving in a number of details that we have found advantageous, such as making the pockets in the combustion-chamber as small as possible and using a good lubricating system. Their carbureters have no wonderful or mysterious features that are not embodied in our own best carbureters. They obtain light weight by building small cars. We have done that, but have found it impracticable for the market. Their large cars attain no better fuel economy than our own best cars. For one thing, they use cars of higher gear-ratios. We have found such gear-ratios unsuitable for our purposes, because we want to do everything on high-gear. We all know that high gear-ratios promote fuel economy. Their connecting-rods are better than ours and they can maintain longer periods of driving on their direct drives, thereby getting better fuel economy.

In regard to advanced design, there was nothing very remarkable, except the Ricardo engine that is being produced now. It was used during the war in a number of tanks. Much is claimed for it in a number of ways. It has a very long piston, in two sections; one acts like an

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ordinary piston and the other as a guide for it. They claim elimination of all condensation of fuel in the crankcase, better lubrication and avoidance of much of the piston friction. I believe that insufficient attention is paid to the losses in piston friction. Designers try to reduce engine weight by using short connecting-rods and thereby add a great amount to the piston friction losses.

The British builders are paying much attention to the small cars, but I could not see that their market is suitable for them. Very small clearance is allowable on the English roads and they certainly can reduce weights a great deal. A small engine will propel five people around very satisfactorily. Their small engines are rated at 11 or 12 hp. One very dominant reason for bringing the horsepower down and using the smaller sizes of engine is the tax of £1 per hp., which is of course a considerable burden to car-owners.

Their mileage per gallon of fuel is based on a better grade of gasoline than we use ordinarily. It is similar to the grade of gasoline we were getting 4 or 5 years ago. Their gallon is the Imperial gallon, which is larger than our gallon; six of our gallons are needed to make five of theirs.

In their high-priced cars there is a tendency to incorporate a number of airplane-engine features, such as aluminum cylinders with steel inserted sleeves. I do not see that we have anything to learn from European practice. We are further along, I believe, in solving the fuel-economy problem and, judging from all I have heard here today and from what I know is going on around the country, we are certainly attempting reduction of weight much more actively and to better advantage.

LEE W. OLDFIELD:—While in France, after the armistice, I had occasion to use one of the Wanderer cars and also to make rather extensive tests with a Petit Peugeot car. Each of these cars has a four-cylinder engine of 60-mm. bore and 90-mm. stroke. The only detail of construction on the Wanderer car that is particularly interesting is that the transmission case is made of steel stampings.

With regard to economy and performance, the Petit Peugeot, which is a slightly smaller car, had a very much better performance than the German Wanderer car. I drove a Petit Peugeot from Paris to Clermont-Ferrand. On one particular stretch, a distance of about 70 miles, we made an average of 28 m.p.h. for about 2 hr. 18 min.

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with this little car. It rode very comfortably. The fuel-consumption was at the rate of slightly less than 7 liters per 100 km., which works out very close to 35 miles per gal. There were no details of particular interest in the engine of either of these cars. They were both magneto-equipped and, generally speaking, of standard accepted design. The Wanderer had silent chains for the front-end drive and the Petit Peugeot had a set of fiber gears. The Petit Peugeot behaved remarkably and will run astonishingly fast. It has direct drive on both second and third speeds. The car is very nearly as fast on second speed as it is on third; I should say there is not a difference of more than 10 m.p.h. One becomes nervous when driving wide-open in second speed, expecting a number of parts to come up into one's lap, but the car continues to go. The gear-ratio is about 7 to 1 on second and slightly better than 3½ to 1 on third speed, with about a 21-in. wheel. I believe the Wanderer car uses a 28-in. wheel. It did not ride or stay on the ground as well as the Petit Peugeot, although it is a car of 100-in. wheelbase, whereas the Petit Peugeot wheelbase does not exceed 60 in.

MR. MANLY:—What is the weight of the Peugeot car?

MR. OLDFIELD:—About 1300 lb., with the load.

CHAIRMAN CRANE:—That comparison of two small cars is very interesting, but I would like to have those present figure the ton-miles per gallon of the Petit Peugeot on the basis of 30 miles per gal. and 1300-lb. car weight. It is easily possible in this country, with cars having maximum acceleration, to do 30 ton-miles-per-gal. On the basis of 1300-lb. car weight, even allowing somewhat extra for two passengers, this car was not doing much over 20 ton-miles per gal. and, after all, the ton-miles per gallon is the real solution as to economy in transportation. I speak of this particular case, in view of the fact that it represents ordinary road conditions, not an attempt to obtain maximum economy. There is a great difference whether we coast every grade we come to with the engine shut off, or leave the clutch in from the time we start until we stop. The 30-ton-miles-per-gal. performance can be and is being obtained in this country on high-acceleration cars, with the clutch engaged from start to stop, the engine throttle being set in the idling position and the accelerator being used during the run. That is very much more expensive in gasoline than under conditions where an attempt is made

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simply for economy and nothing else. I assume this run was made under absolutely similar conditions. I wanted to call attention to the fact that the economy, while actually high in figures, was not really high, especially for a car with limited comfort available.

T. C. MENGES:—I have operated one of the Petit Peugeot cars for several years. The average performance is about 35 miles per gal. on the country roads. The car weighs slightly more than 800 lb. and is a two-seater. It is not well adapted to our country roads. We shift gears even on paved streets. I do not think very well of it as a practical driving car.

MR. MANLY:—In connection with tests on tires, what are the figures as to the actual efficiency of the tires? We have, for example, a certain amount of power going into the tire and a certain amount of work delivered by the tire. What is the efficiency, both as a supporting mechanism and as a straight transmitting mechanism? A number of years ago some tests were made at Cornell University on bicycle tires, but I have not seen recent data of that kind in connection with automotive tires.

CHAIRMAN CRANE:—We produced some very interesting results of that kind, with a drum dynamometer. The rear wheels of the car were run on a pair of drums, the engine was operated and the power delivered at the rear wheels was measured. The results showed an extreme loss in the power delivered by the tires. In the case of one car tested under those conditions, it lost the difference between 45 and 36 hp. in the tires alone. That is a very high percentage of loss in power. Of course, that was in the days of fabric tires. We know that cord tires are very much better.

MR. MANLY:—The figures obtained in the bicycle-tire tests were very surprising as to the low efficiency of certain classes of tire. The efficiency seems to be almost exactly in inverse proportion to the thickness of the tire. The racing tires they were using on bicycles at that time were of high efficiency, compared with the double type of shoes on automobiles; and those tires showed very much better results, compared with solid tires. If we could get some recent data, I know of nothing that would be more interesting on this question than the general improvement of the economy of the tire. We talk about efficiency of the bearings and efficiency of various other parts, when, as a matter of fact, we actually are losing more power in the tires than in anything else in the transmission of the engine power to the rear-axle.

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A. L. CLAYDEN:—Many tests of tires have been made at Yale University by Professor Lockwood. He read a paper[4] entitled Power Losses in Pneumatic Tires before the Pennsylvania Section about 4 years ago, in which he gave the results of a number of tests. I looked at some of the figures a few weeks ago. They show the tire loss is in the neighborhood of one-third of the total. I understand that Professor Lockwood is now getting data together for presentation to the Society this year, and that he has been making these tests with the idea of showing the effect with different sizes of tire carrying the same load.

MR. MANLY:—As regards efficiency, in connection with the matter of tire-inflation pressure, I think these tests will show that the tire is much more efficient when highly inflated. Cars ride more easily when the tires are soft, but I think there will be a tremendous difference in the efficiency when the tire is highly inflated.

CHAIRMAN CRANE:—That is undoubtedly true, but it is also a matter of the efficiency of the casing. In other words, if a perfectly flexible casing could be produced, I think the tire efficiency would be practically the same, no matter what the inflation pressure inside the casing. The fabric tire casing was not flexible; it protested by overheating and blowing up when we did not keep it pumped up. That is the answer to the question as to where the power is being lost. In fact, the tire becomes hot, which indicates that gasoline is being burned to heat it. The only thing there is to heat the tire is the gasoline we burn in the engine. Unfortunately, this wastes gasoline and also wastes tires.

A MEMBER:—I can confirm the remarks made about Professor Lockwood's tests at Yale University. I have run a test recently in which the tires were operated on a drum. This gives a reflex action to the tire. It probably allows somewhat more power loss than would be normal on a flat surface. The tests we have run show that the power loss in a cord tire is 20 to 30 per cent; in a fabric tire it is somewhat higher than that.

W. E. WILLIAMS:—Mr. Putnam mentioned an idea that I think is worthy of serious consideration by the tire-building industry, namely, building a large tire with a thin wall, thus making the tire act in the place of springs to a large extent. In the past the making of a tire that would stand in service has so occupied the attention of

[4] See TRANSACTIONS, vol. 12, part 1, p. 377.

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the tire builders that this feature has been overlooked or little considered; but now that the cord tire allows the individual cords to move more or less independently and with a considerable cushion of rubber between, there is a possibility of making tires larger in diameter with thinner walls and for lower inflation pressure.

Regarding the task of shifting gears and the statement that the car driver prefers to drive in high-gear rather than bother to shift gears, a large amount of brain power has been spent on automatic gearshifting devices. The trouble is that when one goes through any sort of volition to shift gears, even simply to operate a small lever or button, that act causes as much trouble in volitional labor as is demanded to shift the gears actually. The solution of the difficulty lies in simplifying the movement of the present system of gearshifting.

J. A. ANGLADA:—Referring to Mr. Putnam's paper and to Mr. Williams' remarks relative to the elimination of springs and the substitution of pneumatic tires to do their work, with a five-passenger car we probably would use a tire of 12-in. cross-section. I saw a truck that was fitted with 12-in. pneumatic tires. One of the rear tires exploded when the truck was going about 15 m.p.h. One side of the rear went down and the truck turned over. I am inclined to believe that if we use tires of that size on passenger cars we might get the same result in the event of a blowout.

GORDON J. WATT:—Is there any definite and detailed information regarding the French test? It seems to me that the results published in this country do not in any way give proper credit to the American cars. It seems that the French cars had expert handling, and that the American cars had no more than ordinary handling at best and possibly very poor handling. They are doing nothing more to save fuel in Europe at present, at least on the cars in use on the public roads, than is being done in this country. They are getting better mileage, but not better ton-mileage. I think that the publishing of the results of the French tests, without further data, is a bad thing for the American automotive industry and an investigation should be made to see whether those published results conform with the actual conditions of the test. I understand that the French cars have very high compression and everything in the way of special lubrication and the like to make the economy as good as possible.

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O. A. MALYCHEVITCH:—The Petit Peugeot is a first-class car in every way. In France there are good cars and bad cars, just as there are good cars and bad cars here. There is a difference between French and American car design. It is the custom in France, even in the big factories, to entrust the design of cars to special designers. There are three or four such designers in Paris. I have worked with one of them. They look through the old list which is published in every language, so they can collect all the necessary data; then they design the car. There are a few cars which give very good performance, because they receive the best of attention. Everything in that line which the automotive industry of France produces comes from the brains of three or four men. After the design is completed, it goes to the factories. We are more interested in good production. There are two or three cars in the United States that are really refined. Your conditions are quite different from European conditions; so you must not be worried about recent reports favoring French cars as against the American car.

CHAIRMAN CRANE:—We have had experience in this country with economy tests. They were dropped a number of years ago, largely because they did not mean anything. I happen to know the condition of a certain car in one of the last of those tests. The rear-axle gear-ratio was 1½ to 1. The tires were special cord racing tires. The car was lubricated throughout with machine oil; not even heavy oil, far less grease. The engine had a specially high compression. There was a specially small carbureter. The car would start to roll at a touch. My only ride in this car consisted of leaving the factory one day and going ½ mile. The car stopped. We investigated and found that the gasoline was shut off. A few drops of gasoline had been left in the float-chamber and this was sufficient to propel the car for that distance. The actual contest was on a circular course and this car ran out of its scheduled supply of gasoline a little more than one-half way around. It had 1 gal. to operate on during the race, and was provided with 2 gal. to get home on. It did not get home but ran out of gasoline and had to be towed in.

H. L. HORNING:—It appears that Americans are just beginning to realize the importance of the friction losses in an engine. These losses establish the mechanical efficiency of the engine. Roughly speaking, it requires as

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much power to run some engines using heavy oils as it does to run the car along the highway. Thus, 50 per cent of all the power developed is lost. This is a very bad showing. A case which I have in mind is that of a 4½ x 6¼-in. engine having a 398-cu. in. displacement. Considering this engine at 1000 r.p.m., the following facts are important.

Grade of Oil	Pull, lb.	Friction Pull, lb.	Brake Mean Effective Pressure, lb. per sq. in.	Brake-Horse-power	Mechanical Efficiency, per cent
Vacuum Arctic	184	16	92	46	92
Vacuum A	180	20	90	45	90
Vacuum BB	170	30	85	42	85
Vacuum B	160	40	80	40	80

The most effective study can be put on piston design, to reduce the mechanical losses in the engine. The losses due to shearing the oil-film can be considered as about 50 per cent of the total losses, at 1000 r.p.m. An hydraulic pressure of 10,000 lb. per sq. in. is developed in an oil-film which cannot escape the rolling-up action such as occurs between the piston and cylinder wall at high speed. Grooves on or holes in the piston relieve the pressure. Recently I tested an efficient automobile engine which had the following satisfactory characteristics.

Engine Speed, r.p.m.	Mechanical Efficiency, per cent	Fuel-Consumption, lb. per hp-hr.	Brake Mean Effective Pressure, lb. per sq. in.
600	92.5	58	72
800	91.0	54	75
1,000	90.5	55	78
1,200	90.0	55	78

With an engine of this type in a car weighing 3000 lb. empty, it is not impossible to make 24 miles per gal., or something over 38 ton-miles per gal. I feel that this is a very creditable performance when compared with the ton-miles per gallon and even miles per gallon of some of the smaller European cars referred to.

O. C. BERRY:—To add to Mr. Horning's remarks about the amount of power required to propel a car on the road as compared to the power used up in engine friction, I would say that I have recently tested a car weighing 3100 lb. including the driver and observer, and having a maximum of 3.1 ft. per sec. per sec. acceleration. It required 3.51 hp. to turn the engine over at a speed of 1000

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r.p.m., with the throttle set as it would be set in driving at that speed, while only 2.85 hp. was required to propel the car at the corresponding 20 m.p.h. on a hard level road. These figures are characteristic of our "active" American cars, and help to show why so much better mileage can be obtained when the speed of the engine is reduced at the expense of accelerating power. The results of the recent economy tests in France were an eye-opener to me. A Voisin limousine weighing 5300 lb. made 28.3 miles per American gal. This looks high when compared with the customary performance of our American cars, and goes to show what the possibilities are in the way of improving our fuel economy.

I do not agree that an economy test is of no value. I grant that when some particular carbureter is used and adjusted for a certain car at a given speed to obtain the maximum possible mileage, regardless of performance, the results have little or no value. Before the economy test is started it should be required that the car meet very carefully specified performance tests. Under these conditions the results take on a real value. I would like to see the Society of Automotive Engineers, or some similar organization in this country, back up a series of economy tests occurring once a year. I feel convinced that they would result in a real benefit to the industry. It appears to me that the matter of fuel economy has received less study than any other one feature of the American car. This is a mistake. We are in danger of a fuel shortage, a time when not all of us can ride for want of a sufficient amount of fuel, and those of us who do ride will pay well for our pleasure. The price of our fuel will tend to follow one of two standards. When the raw material is plentiful and can be had by anybody, the price of the finished product will be the cost of production plus a reasonable profit. As soon as the demand exceeds anything that can be produced from the raw material, the price tends to rise until it represents all that we are willing to pay. The French are paying about $1.90 per American gal. for their fuel. If such prices were demanded in this country it would have a serious effect on the whole automotive industry, and such prices are inevitable in the not distant future unless vigorous steps are taken. Hence the great value of any effort that will result in better economy on the part of our American cars.

The foreign engines do not have incorporated in their

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design any features resulting in high economy that we do not understand, nor do I feel that the American engineer is one whit less resourceful or well informed than the best in the world. I want to see us make a careful and exhaustive study of all the factors influencing fuel economy and set ourselves the task of exceeding the best results ever obtained by the English, French, German or Italian engineers. We ought also to go one step farther and design our cars so that the average driver can approach ideal results more closely than he can at present.

CHAIRMAN CRANE:—I think that Mr. Berry is right regarding the educational value of economy tests at this time, provided a scientific basis could be arranged for them. There is nothing like trying to get the maximum mileage per gallon of fuel out of a car. I hope the matter will be taken up and an attempt made by the proper authorities to formulate a set of rules for an economy test that will really cover stock cars and also what we might call stock driving. In the old economy test the driver was allowed to do anything he chose, and that resulted in a method of driving which is never used by the public. The cars, equipped as I have described them will coast readily on a grade of about 2 per cent and keep it up indefinitely. They do this very slowly it is true, at 10 to 12 m.p.h., but with the engine shut off, that gains mileage at a great rate.

Our company started some years ago to put speedometers just back of the transmission. After watching this practice very closely for a long time, I do not agree that there is any serious discrepancy between the mileage run by the rear wheels and the front wheels, in ordinary service. That was indicated by tests made at the Brooklands race track in England; the difference was remarkably slight, and I imagine that this track was not particularly smooth in those days. The relatively short intervals of time between bumps on the road are not sufficient to make any noticeable change in the angular velocity of the driving-wheels.

E. W. WEAVER:—If the engine is kept running wide-open at a speed to develop the power that is actually required, we will get the greatest economy that it is possible to get. For instance, if it requires 2½ hp. to run the engine, if we could run it slowly enough so that 2½ hp. is all the power it actually develops, we would get a much greater economy. A series of tests shows that

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very plainly. That would be equivalent also to having gear-ratios that will allow this in the end.

CHAIRMAN CRANE:—There is no question that this is an absolute fact with the Otto-cycle engine. The more slowly it runs, the less the mechanical loss is; the higher we keep the compression, the better the thermal efficiency is. So, there is every reason to run the engine as slowly as is possible to develop a certain power. The only limitation to this is based on the ordinary design of engine that will not run below 100 r.p.m. and give any satisfaction at full load.

W. C. DAVIDS:—In regard to the transmission and the shifting of the gears, that requires so much strength and acrobatic action, would not the hydraulic transmission eliminate this?

MR. WILLIAMS:—The hydraulic transmission was made successfully over 20 years ago, originating in Minneapolis. It was tested in New York City and showed a power loss of only 15 per cent. They undertook to use it commercially in automotive vehicles, but it would heat up. Not only that, but any bit of sand or grit in the oil would be forced around with the oil through the passage-ways and cut them out. They did use that transmission to get any variation of speed and adjustment in lining up the guns on the United States battleships. There is one vital failure attendant upon the hydraulic transmission. You must still shift something for speed changes and must still control the engine. It is simply a change in gearbox arrangement.

MR. MANLY:—I have spent about 20 years and much money on hydraulic transmissions. They are being used today in turning the guns on American battleships and are very useful and effective. I have also built some for use on large motor trucks, for moving draw-bridges and other work of that kind. In regard to the heating effects, that is a difficulty which must be taken care of, but it can be overcome. As the temperature rises, the viscosity of the fluid must decrease. We have not found any fluid that does not have that characteristic but, on the other hand, the hydraulic transmission is not in the same category as the friction transmission. In connection with the matter of increasing the torque as the speed decreases, we can give an exact increase of torque, with a decrease in the speed, up to any predetermined point. It is merely a matter of design. Something will be accom-

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plished in connection with hydraulic transmission, especially for heavy work.

In regard to the light passenger-car, during the past 20 years I have been attempting to apply the hydraulic transmission but have found that it is not necessary with it. However, in regard to heavy work such as is required of trucks, tractors, road rollers and the like, I think the hydraulic transmission has a very large field. I presented a paper[5] before the American Society of Mechanical Engineers, in 1911, and one before the Automobile Club of America in 1912, which give rather interesting data in connection with this subject. The fault that Mr. Williams criticized in connection with the design he looked at can be overcome.

MR. WOLF:—Referring to Mr. Williams' question about the pump wearing out, I would say that in the particular system mentioned the pistons force the oil out as they come toward the center. Each piston-head was cupped and all foreign matter and sediment would collect in the cup, due to centrifugal force. It was found that this in no way impaired the working of the system. In fact, when dismantled after two or three years of service, all parts were found in good order. The cylinders and pistons were free from scoring. The piston-heads held considerable grit.

It is probable that chassis weight can be reduced still further by more extensive use of alloy steels. Due to its superior characteristics under proper heat-treatment, molybdenum steel is likely to receive the attention of those who are anxious to eliminate excess weight. It seems to me that in frame construction, for instance, effort in this direction will equal or surpass any result that might be obtained by the use of plywood, and at the same time make a far better manufacturing proposition. Rather than resort to extreme means, of which I consider plywood one, I think it would be better to expend the same energy in refining what we already possess.

With reference to the churning of the grease in the transmission, I believe that we should design the transmissions with a small circulating pump so that it can handle light oil and deliver it to the face of the gears. Many years ago the De Dion car introduced such an arrangement and it is now used in a number of tractors. The same recommendation applies to the rear-axle, where an oil-pump can be added, or the two applications can be

[5] See *Transactions of the American Society of Mechanical Engineers*, vol. 33, p. 851.

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worked together. The pumping loss will be far less than the drag of the grease, especially when the grease is cold.

It was stated that when a wheel goes over a rough road, the wheel would not accelerate due to its inertia. This flywheel effect undoubtedly is considerable, but another thing to be considered is the action of the differential. The conventional differential is too efficient, although it sounds paradoxical to condemn efficiency. When one wheel leaves the ground, the engine tends to speed it up through the differential; this has been observed in high-speed motion pictures that have been slowed down. In one particular case a truck rode over an obstacle probably 5 in. high and, when the one wheel left the ground, one could easily see it accelerate. If this happens with the truck wheel having so much greater mass, it must occur in the case of the lighter passenger-car wheel, and I believe that energy is wasted and tire wear increased by this action. It would be better if differentials did not function when the vehicle is traveling straight ahead, but only when making turns.

I believe that a constant-speed engine with a widely variable transmission system would not result in the engine being used continually at a constant speed. Other systems have indicated this. What we desire most in this combination is the variable transmission-ratio, rather than the strictly constant engine speed. In this way we could approximate more closely the desirable results stated by Mr. Nelson in his paper on the Fuel Problem in Relation to Engineering Viewpoint.[6] A great portion of the time that a car is on the road, the engine can easily handle the load on a higher gear-ratio; and, if a practical widely variable transmission were available, it would go far toward solving the fuel problem by working the engine nearer its point of maximum efficiency. For the variable conditions encountered on the road, the present limited gear-ratios are not variable enough to obtain the best efficiency of the engines.

In regard to changing gears, which is a thing that the American driver does not like to do, I believe that if we could have silent operation this would help toward making the public willing to do more gearshifting. There is undoubtedly considerable embarrassment to the ordinary driver who does not wish his friends to know that he must negotiate a grade in one of the lower gears. The noise also produces a mental strain on the driver.

[6] See p. 325.

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RESUME OF BUREAU OF STANDARDS FUEL STUDY

By H C Dickinson

The author states that considerable thought has been devoted recently to the relation of fuel end-point to fuel economy. It has been shown that, provided an intimate mixture of fuel-vapor and air is secured, such a mixture will not condense at the ordinary temperatures of the intake. However, on the contrary, crankcase dilution, an excess of deposited carbon, low mileage per gallon of fuel and ignition trouble are being experienced. There appears to be a discrepancy between the efficiency that should be attained and what is actually attained. To investigate this the Bureau of Standards undertook a brief series of experiments to rough out a line of procedure.

Regarding compression of a dry mixture, curves are shown to illustrate that gasoline vapor compresses when "dry." Detonation was evident when using one spark-plug and there was no detonation when using two spark-plugs. After preliminary experiments of the nature already indicated, a pressure indicator was used, at pressures just on the verge of detonation, to find the exact point where detonation occurs. Charts are exhibited to show the location of the piston with reference to its center position, with one spark-plug and with two spark-plugs; and the effect of spark-advance on the maximum explosion pressure and brake-horsepower, using one spark-plug. An explanation which goes into considerable detail supplements the charts.

Regarding the problem of the relation between distillation range and fuel econmy, there has been considerable thought devoted recently to the relation of fuel end-point to economy. Mr. Howard's very interesting paper on the subject of Volatility of Internal-Combustion Engine Gasoline[2] shows conclusively, I believe, that provided we secure an intimate mixture of fuel-vapor and air, such a mixture will not condense at the temperatures of the intake with which we are working. However, over against this we have the evident fact that at present we

[1] M.S.A.E.—Physicist in charge of powerplants research, Bureau of Standards, Washington.

[2] See p. 274.

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are having crankcase dilution, excessive carbon deposit, low mileage and trouble with the ignition. All of these are manifestations of excess fuel-consumption. Therefore, it seems that there must be some gap in the explanation somewhere; in other words, what we should get does not tally with what we do get. It was with the view of throwing a little light on this discrepancy that the Bureau of Standards undertook a brief series of experiments to rough out, so to speak, a line of investigation. Before taking up this question, however, I wish to present a few observations on another subject.

A question often raised and which apparently has not been definitely answered regards the effect of compression on the dryness, or dew point, of the mixture of fuel and air. To develop definite figures on this subject, we have looked up such information as is available in published form and submit this in the form of a set of curves.

Fig. 1 shows that gasoline vapor compresses "dry." As Mr. Howard pointed out, each of the components in commercial gasoline has a definite vapor-pressure at a definite temperature and, above some particular temperature, each one of the components will exist in the form of a vapor when mixed with air in any given proportion. Taking the rough assumption that the proportion of vapor to air is about 2 per cent by volume, we have at the left of the diagram a series of curves which represent, for several of the substances for which figures are available, the relation between the vapor-pressure of the substance and the temperature, and at the right, adiabatic-compression curves are plotted in millimeters of mercury and degrees centigrade, showing the pressures and temperatures for these same substances when mixed with air in the foregoing proportion. The various curves are plotted for different initial temperatures. The diagram is drawn so that at any point where the left-hand curves representing the various substances are above the adiabatic-compression curves, the mixture will be dry; if they are below, the fuel will condense. The point of particular interest is that the adiabatic compression of a mixture invariably makes it very markedly dryer, so that there is an opportunity for vaporizing fuel to a considerable extent in the cylinder, due to compression alone. Thus a fog mixture of decane and air in the proportion of 1 to 15 and at 32 deg. fahr. if compressed to slightly less than half its volume will become dry. If the compres-

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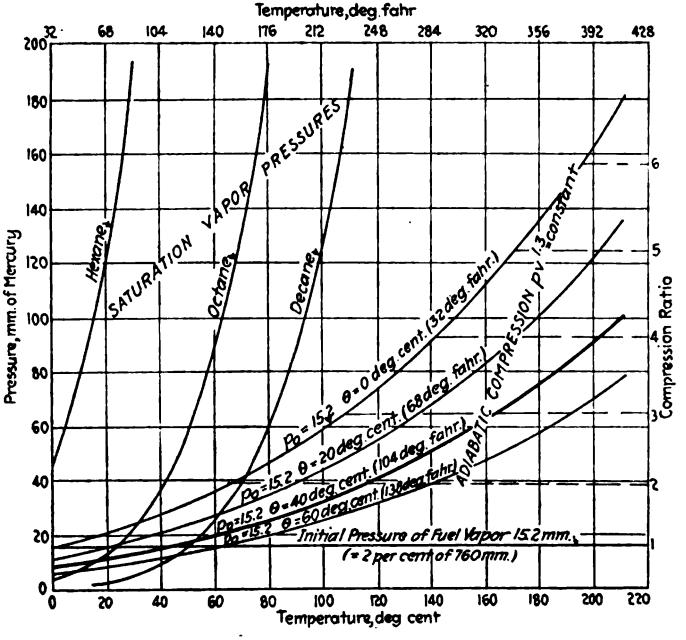

FIG. 1—SERIES OF CURVES SHOWING THAT GASOLINE VAPOR COMPRESSES DRY

sion were to take place at a constant temperature rather than adiabatically, the result would be entirely different, the fuel being condensed rather than evaporated.

FUEL CHARACTERISTICS AND ECONOMY

To throw some light on the relation between fuel characteristics and economy experimentally, we undertook a brief series of experiments with the equipment which was used for the report presented by Mr. James[3] last summer. I present the results with the belief that they do not represent truly what is average practice, but that they may point out certain limits which have not been well recognized before. The equipment referred to is a six-cylinder engine coupled with a dynamometer. It has a hot-spot manifold, equipment for measuring and controlling temperatures and pressures and for making such measurements as are desired, including measurements of acceleration.

I assume that typical driving conditions can be repre-

[3] See TRANSACTIONS, vol. 15, part 2, p. 170.

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sented by a car speed of 20 to 25 m.p.h. and a horsepower which about corresponds to the average load of a car on the level at that speed. Typical conditions also involve very frequent acceleration; accelerations, for instance, of from 10 to 30 m.p.h. and, under these conditions, with an intake-air temperature which is likely to be about 60 to 70 deg. fahr. and a normal amount of heat on the intake-manifold. In these experiments, the hot-spot on the manifold was cut out by blanking it off with a piece of asbestos, inserted between the intake and exhaust-manifolds. The immediate object of the experiments was to determine the difference, if any, in the amount of fuel burned to perform a definite amount of service under typical driving conditions as represented above, for three grades of gasoline; first, with aircraft gasoline, then with commercial gasoline and finally with aviation gasoline containing about 15 per cent of kerosene.

Two main types of experiments were undertaken. These were (*a*) steady runs to determine the rate of fuel consumption under load conditions, at about one-fifth the maximum mean effective pressure and a speed of 1200 r.p.m. and (*b*) a series of repeated accelerations from 10 to about 30 m.p.h. In each case the fuel consumption was recorded. The constant-speed runs were all made at the same speed and load and for the same length of time with special care exercised as to the conditions of air, water and oil temperature, so that the total number of horsepower-hours was as nearly as possible the same in all cases.

The acceleration runs each consisted of a series of accelerations following a period during which the engine idled with a closed throttle. The idling speed and adjustment and the stop to which the throttle was opened on acceleration were carefully regulated to assure the same engine speed on idling and the same throttle opening on acceleration for all runs. The idling and acceleration periods followed the same scheduled sequence and were of the same duration in all cases.

The load on the dynamometer depended upon the speed as determined by the characteristics of the dynamometer, the torque being nearly proportional to the speed. The control rheostats were adjusted the same in all cases; hence, the total horsepower-hours developed in all the acceleration runs were substantially the same. A watt-hour meter was not available but would have been desirable as a check on the equality of power output.

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The schedule for each acceleration run was as follows:

(1) Adjust throttle to idle at 500 r.p.m. and adjust acceleration stop to give a speed of 1500 r.p.m.
(2) Idle for 30 sec.
(3) Open throttle to stop and observe time required to reach 1200 r.p.m.
(4) Maintain this speed for remainder of first 60 sec.
(5) Close throttle to idling position at 60 sec.
(6) Open to acceleration position at 90 sec.

The series was repeated five times.

The dynamometer equipment includes two fuel tanks arranged so that they can be supplied with different fuels and the supply to the engine quickly changed from one to the other.

In these experiments two of the three fuels, first aviation gasoline and commercial were supplied and a single run, as described above, was made, first with aviation gasoline with a selected carbureter adjustment and repeated with commercial gasoline and the same adjustment; then the carbureter adjustment was changed to a leaner one and a run taken with commercial gasoline, then with aviation gasoline and the same adjustment. In this way five values of mixture-ratio were run, the fuels being alternated between each pair of runs. A series of comparisons was similarly made between the aviation gasoline and this fuel plus 15 per cent of kerosene.

The results of these runs have been rather carefully tabulated, but an examination of the tabulation yields one result, namely, that for the conditions here adopted there is no significant difference in the total amount of any of the three fuels consumed, reckoned in pounds, to deliver the same amount of horsepower-hours under the same conditions. I wish to repeat that I do not believe that these observations show that the fuel consumption in service is independent of the fuel composition. They do show, however, that the induction system of the particular engine used for these tests was unusually good, as the intake temperature was only about 125 deg. fahr.

What Is Detonation?

There has been much discussion as to precisely what the phenomenon of detonation really amounts to physically; as to the precise physical performance inside an engine cylinder when it develops the sound which we call detonation. Some of our colleagues at the Bureau

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of Standards have been inclined to question very carefully every proposal which has been set forth. Mr. Sparrow suggested some time ago that he wanted to prove whether what we recognize as detonation or fuel knock could not after all be an aggravated piston slap. We have a one-cylinder Liberty engine which has served many experimental purposes. This engine was fitted with a piston about 1/10 in. too small in diameter which produced a most aggravating slap, as was intended. There being no doubt about the presence of the piston slap, we stood some chance of finding whether the detonation and the piston slap were the same or not. After some adjustment, it was possible to get detonations in conjunction with the piston slaps. The two things are distinguished very easily and no other proof seems necessary that they are entirely independent.

Following these observations we became interested in recording some of the facts, or apparent facts, which can be established with regard to the phenomena of detonation, particularly those which can be verified by physical measurements. The one-cylinder Liberty engine is admirably adapted for such observations as the parts can readily be replaced and it can be modified to meet experimental conditions. The cylinder at present in use is fitted with openings for three spark-plugs, permitting at least one to be used for experimental purposes such as mounting an indicator or a window for looking into the cylinder without interfering with ignition. When observing the conditions which affect detonation, it is desirable to make these observations under conditions such that detonation is just on the verge of occurrence or non-occurrence. Under these conditions the phenomenon is most sensitive to changes in conditions. Accordingly, all observations discussed hereafter were made with the engine throttled to about 60-lb. mean effective pressure and a speed of approximately 1100 r.p.m. Under these conditions, the cylinder developed 10 to 11 hp. and detonation was easily brought in or prevented by slight changes in the conditions of operation. Commercial gasoline was used in most of these experiments.

One of the most significant features of the phenomenon to me is its discontinuity. By discontinuity I mean that the detonation knock is as definite a physical thing as the explosion; it either occurs or it does not occur. When it occurs it occurs with considerable violence; and when it does not occur it is entirely absent. In this sense, there

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is something in the phenomenon which is in the nature of a physical discontinuity; it fires or it does not. To illustrate, if we gradually increase the intensity of the spark in a cylinder which is being fed with fuel mixture, the charge will not fire as long as the spark is too weak, but at some point it will begin to fire irregularly; some strokes will be accompanied by an explosion, while others will not. Similarly as regards detonation, some strokes are accompanied by it and some are not, and it is usually very easy to distinguish between them, although the intensity can be varied widely.

For the most part, observations were made with the conditions substantially constant, except for changes in the timing and changes from one to two spark-plugs. The water temperature was maintained at about 70 to 75 deg. fahr. constantly; the mixture ratio was kept constant under all conditions, and carefully checked to see that it did remain constant. It soon developed that it was very easy to get a perfectly definite detonation with one spark-plug and no detonation with two spark-plugs, all other conditions remaining fixed. That has been noticed many times and is explained naturally by the theory of the detonation waves. But, carrying it further, Mr. Sparrow showed that it is almost as easy to get detonation with two spark-plugs, while not with one spark-plug. That is not so simply explained on the basis of the accepted detonation-wave theory, although the fact may prove to be consistent with this theory.

The most obvious conclusion from these experiments is that, whatever the nature of detonation, it is largely dependent upon the timing of the explosion with respect to the position of the piston. This does not mean necessarily the timing of the ignition spark, but rather the time at which the maximum rate of burning takes place. For instance, when firing from two spark-plugs at opposite sides of the cylinder, the maximum rate of burning will occur a much shorter time after ignition than when firing from a single spark-plug. If, therefore, the ignition time is the same in the two cases, firing from two plugs instead of one will in effect advance the ignition and vice versa.

Thus, if the ignition timing in the present experiments was such as to produce detonation with two spark-plugs, cutting out one plug had the effect of retarding the time of burning sufficiently to prevent detonation. On the other hand, if the timing was such as to produce

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detonation with one spark-plug, cutting in a second plug had the effect of advancing the time of burning and preventing detonation by this means. These effects are shown in the several illustrations described below.

Another phenomenon noticed is the fact that the temperature of the jacket water, or the heat lost to the jacket, was materially affected by the fact of detonation or not. The intake water for this engine was kept at a nearly constant temperature and the rate of flow was substantially constant; consequently, it was easy to determine roughly the amount of heat supplied to the water-jacket by measuring the temperature of the outlet water and, under all conditions where detonation was produced, a very marked rise of temperature in the jacket developed. I believe that the actual amount of heat supplied to the water-jacket was in some cases almost 30 per cent greater when detonation was produced than when it was not produced. Accompanying that increase in heat to the jacket there was usually a small dropping off in the mean effective pressure, but the dropping off in the mean effective pressure by no means accounted for the actual extra heat lost. The source of the apparent extra energy, as well as the general effect of detonation on heat distribution, might be worth careful consideration.

Further Detonation Experiments

Following the foregoing experiments, an indicator was mounted on the cylinder and a series of indicator-cards was taken under varied conditions to throw more light on the exact conditions accompanying detonation. It should be borne in mind that all these experiments were carried out at pressures which were just on the verge of detonation. Most of the observations which have been made along this line have been at full load and under conditions where the maximum pressures often were considerably higher than is necessary to produce this phenomenon. With compressions barely high enough to produce detonation, it might be expected that the phenomenon would be much more sensitive to pressure and ignition timing than if we were working under less carefully controlled conditions. Even at these compressions, maximum pressures in the cylinder of far above 1000 lb. per sq. in. were developed repeatedly. Incidentally, the pressure on the wrist-pin was somewhat over 8000 lb. per sq. in.; I believe it was 10,000 lb. per sq. in. in some cases.

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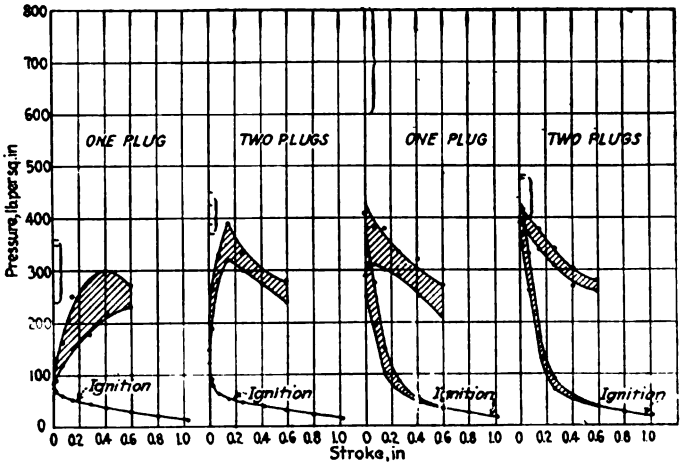

FIG. 2—CURVES SHOWING THE MAXIMUM EXPLOSION PRESSURES DEVELOPED WITH ONE AND TWO SPARK-PLUGS

The curves in Fig. 2 were plotted in terms of the distances of the piston from its center position, in tenths of an inch. The point of ignition is shown on the various curves. The shaded area represents the area between which the maximum and the minimum pressures occurred in any cycle. The indicator we are using is one which enables us to plot the maximum, minimum and intermediate pressures in the cylinders, for each position of the crankshaft. The brackets to the left indicate the range of maximum pressures which were measured, independent of the position in the stroke. In the two curves at the left, the ignition time was the same but the time of burning was advanced in the second case due to ignition by two spark-plugs instead of one. The next curve to the right was produced with one spark-plug. The much higher peak pressure should be noticed in this case. The detonation knock was present in this instance and the bracket at the top shows the presence of very high maximum pressure, accompanied by very marked detonation knock, in fact, an intolerable noise. The curve farthest to the right represents the absence of detonation with two spark-plugs, the ignition timing being the same as for the previous curve. Ignition is obviously too early in this case as shown by the shape of the curve at the maximum pressure, but little or no knock was observed.

Fig. 3 shows similar curves that were all taken with

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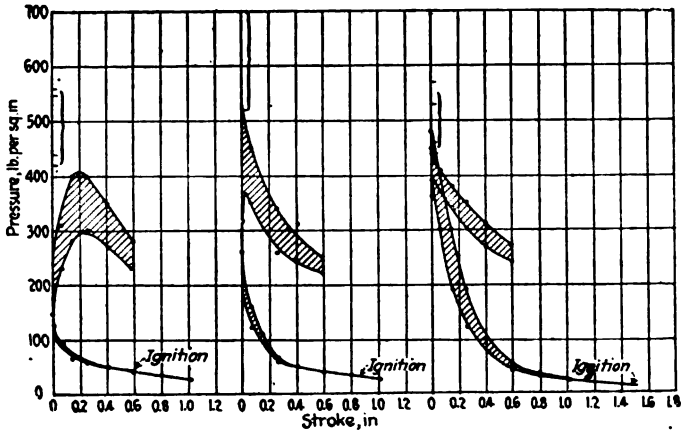

FIG. 3—A SERIES OF SIMILAR CURVES TAKEN WITH THE SINGLE SPARK-PLUG

The Curve at the Left Represents the Maximum Power, That in the Center the Maximum Detonation and the One at the Right the Effect of a Moderate Preignition

one spark-plug. The curve toward the left represents normal burning. The point of ignition is 0.6 in. below top dead-center. The first curve represents the maximum power and the second represents the maximum detonation with the single spark-plug. In this case the maximum pressure range is 500 to 700 lb. per sq. in., the normal compression range being 375 and 525 lb. per sq. in. This curve represents a marked loss of horsepower, as compared with the former. The third curve represents the effect of moderate preignition; then the pressure drops during the dead-center period, due to cooling of the cylinder walls or to leakage. This drop of pressure during the compression period may be due partly to actual leakage and partly to cooling of the charge, which is at a very high temperature. It should be noted that the maximum pressures as indicated by the brackets are only about the same as in normal operation, as shown by the first of the three curves, and the knock is no more pronounced.

Fig. 4 is plotted to show the relation between spark timing and the maximum pressures reached in the cylinder; also the power output. The upper curve represents the range of maximum pressures which occur in the cylinder versus the spark timing. For instance, at a 20-deg. advance, the pressures ranged from 265 to 390 lb. per sq. in. and with a 40-deg. advance, the pressures were highest. In comparing these with the power out-

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put, it is seen that at 15-deg. advance or slightly more, the power was maximum, and at 40-deg. advance, there was a drop of from approximately 12 to 8½ hp., accompanied by an increase of more than 100 per cent in the maximum pressure.

Fig. 5 is the same as Fig. 4, except that instead of being plotted in degrees, the timing is plotted in inches from top dead-center. Both the lower and upper limits are almost straight lines, on both sides; that is, they show almost a linear relation between the position of the piston and the maximum pressure. The maximum power is secured at an ignition point of about 0.3 in. below

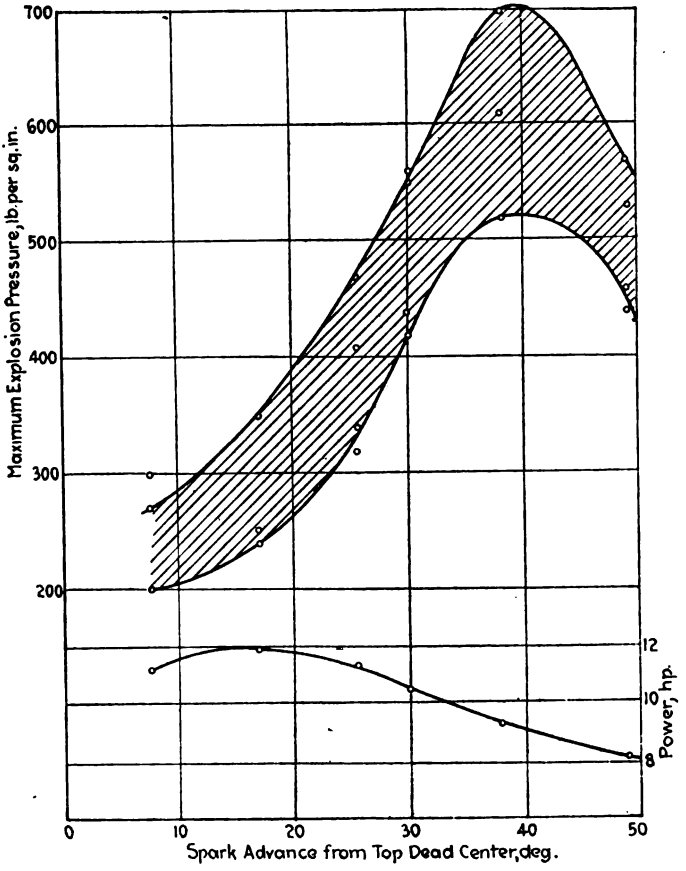

FIG. 4—CURVES SHOWING THE RELATION BETWEEN SPARK TIMING AND THE MAXIMUM PRESSURES REACHED IN THE CYLINDER

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dead-center. Detonation takes place most severely at the point of maximum pressure. This suggests, in this case at least, why it is possible to get detonation with two spark-plugs and not with one spark-plug, and vice versa, depending upon the timer setting.

Fig. 6 gives the data plotted in Fig. 3, in pressure-time coordinates. Hence the curve to the left represents normal conditions, the middle curve the maximum detonation as produced by change of spark-timing alone, and the right-hand curve shows the characteristics of too early ignition.

The foregoing are only a few of the facts and fancies

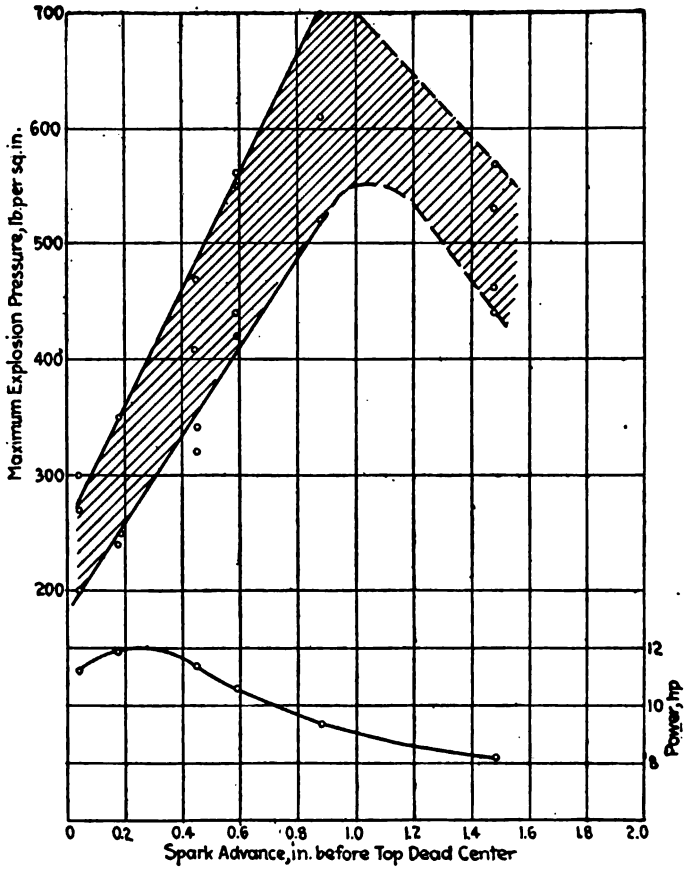

FIG. 5—A SET OF CURVES SIMILAR TO THOSE GIVEN IN FIG. 4 EXCEPT THAT THE TIMING IS PLOTTED IN INCHES FROM THE TOP DEAD CENTER INSTEAD OF IN DEGREES

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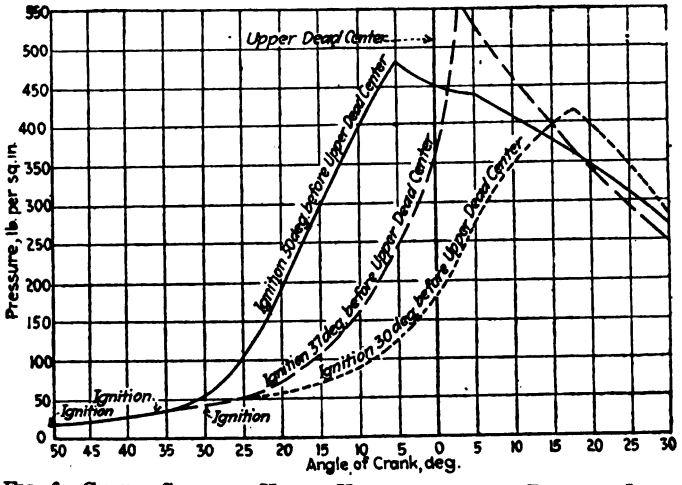

FIG. 6—CURVES SHOWING HOW A VARIATION IN THE POINT OF IGNITION CHANGES THE MAXIMUM EXPLOSION PRESSURE

regarding the phenomenon of detonation. There is much more that we think we know and still more that we think we can see and hear. We may never acquire a complete and definite knowledge of the real nature of the phenomenon, and it might be of little practical value if we did. So long as such an obvious and important problem remains unsolved, we can hardly cease to look for its solution and to hope that when found the solution will be of importance commensurate with the complexity of the problem.

THE DISCUSSION

E. A. SPERRY:—There is a possible explanation of the extra heat loss to the jacket at the moment of detonation. Mr. Midgley and Mr. Kettering have always found a deposit of carbon in the cylinder or exhaust caused by detonation. Also, there is seen through the window a brilliant light at the time of detonation. Inasmuch as radiation is as the fourth power of the temperature, it occurred to me that the black-body radiation of the carbon particles present might help to explain the extra loss of heat to the jacket.

THOMAS MIDGLEY, JR.:—That is a reasonable explanation but we have one or two other points to consider. We have studied the spectrum of the light through a window in a cylinder-head and watched the light of combustion from many different fuels. It is true that with

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kerosene or gasoline the light is very intense during detonation, as compared with a comparatively weak light when there is no detonation; but with benzol as a fuel, it being rich in carbon, the light is just as bright as during detonation, although there is not the heat or pressure that there is during detonation. I suggest as a possible explanation that in knocking, which is a differential burn of the hydrogen that leaves the carbon behind, the carbon is actually in a gaseous condition following this rather active period. If a piece of steel is put into a steam bath of 212 deg. fahr. and another piece is put into hot air at 212 deg. fahr., the piece that is in the steam bath will heat up more quickly than the one that is in the hot air. If we have gaseous carbon in a detonating explosion, it is certain to produce heat more quickly than simply some hot solid particles.

We encountered a condition in which we had a definite green-band spectrum with the spectroscope during knocking. My colleague said that this showed carbon. We hope to have some definite information about this spectrum ready for the Summer Meeting.

FRED WEINBERG:—I do not believe in Mr. Midgley's theory. We have been unable to gasify carbon; it has never been done. We were, however, able to melt carbon, two years ago. The condition under which carbon melted was the extreme high temperature of the electric arc, in a vacuum. Under ordinary atmospheric conditions carbon will not melt.

L. M. WOOLSON:—I think we must acknowledge that Mr. Nelson's paper is one of the most complete ever read on the subject and that he should be complimented for the very full presentation of data which less broad-minded members might consider confidential and in the nature of trade secrets. I am inclined to take issue with Mr. Nelson with regard to his theory that we need a change of viewpoint. What we actually need is closer concentration on our detail problems. We have been spending most of our time in developing engines for next year's market, adding accessories from time to time. These have included electric starting and lighting, or even electric gearshifts. We have tried all kinds of valve arrangement and drive, starting out perhaps with an L-head engine, testing every other conceivable arrangement and then probably finishing up with an L-head design. Now that these matters are all settled, we have some time available for meeting the problems presented

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by the cars that are now in service. Most of us are trying to increase the gasoline mileage of our cars; there is, of course, the bogey of gasoline shortage to urge us on in our work of conserving fuel. The advertising departments of various motor-car builders have done some splendid work in securing high gasoline-mileage, on paper. Mr. Nelson has done better, showing that we can secure nearly 50 miles per gal., if we use rear-axle ratios that will rob the car of most of its performance on high-gear, and high-compression engines which will knock badly with ordinary fuel. Nevertheless, I would not accuse Mr. Nelson of being visionary; he ought to be congratulated on setting up a target for us to shoot at, even though we need long-range guns to hit it.

There is one rather important point in the matter of fuel saving that Mr. Nelson has not touched upon and warrants most thorough investigation. In the test shown in Fig. 23 of his paper he gives a fuel consumption of 1.125 lb. per b.hp-hr. at 1000 r.p.m. of the engine, which represents average driving conditions. It is perfectly possible to reduce this consumption to about 0.93 lb. per b.hp-hr., representing a gain of something like 20 per cent in gasoline mileage. All we have to do to obtain this additional mileage is to construct carbureters that will give a lean mixture under average driving conditions, and this can be done without hurting the acceleration or wide-open pulling. Most carbureters are designed to give practically a constant air-gas ratio throughout the range, although experience has shown that this is not required in actual operation. While this possible 20-per cent saving is small in comparison with some of the savings pointed out by Mr. Nelson, it is within our reach without any accompanying disadvantages.

Mr. Nelson does not offer any conclusive evidence that sufficient heat is furnished to the mixture under average driving conditions. The ability to accelerate well in cold weather without pulling the choker soon after starting certainly does not prove the point. That depends on how rich a mixture the carbureter was set to furnish at the time. Although I have been for some time in favor of rather higher intake-mixture temperatures than are usual, it is only recently that I have found that still higher temperatures are desirable from the standpoint of maximum economy and maximum performance in acceleration. I believe that we should refer to actual in-

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take-mixture temperatures when we discuss methods of fuel vaporization, instead of to car performance in a general way or to other less specific data. There is no question that there is a certain desirable range of mixture temperatures that will probably apply to all engines under the same conditions, and I believe we ought to know what that range is. The Bureau of Standards has shown that greatly improved acceleration can be obtained by raising the mixture temperature, but I believe it has not investigated or at least reported the great gains in economy possible under ordinary driving conditions with mixtures at rather high temperature, given, of course, suitable carbureter adjustment. I venture to say that the desirable temperatures will be found to be about 100 deg. fahr. above those obtaining in the average intake-manifold.

It appears that there will be considerable variation in opinion as to the significance of actual manifold-temperature measurements. As pointed out by Mr. Howard, it is not desirable to heat the air unduly, but it is necessary to apply fairly high temperatures to the fuel. In one case we may have an average mixture-temperature of 120 deg. fahr. and a relatively poor degree of vaporization, and in another case with the same average temperature almost complete vaporization. Nevertheless, we must determine the best average mixture-temperatures under different conditions, and Mr. Horning's suggestion that these be determined in terms of carbureter efficiency is a real constructive step. This work is to be undertaken by the Bureau of Standards and the Bureau of Mines in the immediate future, if the necessary funds can be secured.

Mr. Nelson made some rather positive statements regarding the value of certain types of aluminum piston, which I believe should be accepted with reservations. It is only after we have had a great amount of operating experience under average driving conditions that we can be sure of our ground in a case such as this.

A. L. NELSON:—I am glad that Mr. Woolson is inclined to take issue with me relative to a change in engineering viewpoint. I believe we have been doing for years what Mr. Woolson suggests; nevertheless, we have perhaps paid too close attention to mere details and our feet are not yet touching the ground when it comes to the fundamentals underlying our problems. Mr. Woolson gives a rather unique picture of the development of a certain

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new engine which started out with an airplane birth, so to speak, and wound up in a rather conventional L-head type, the type that has been in use for years, particularly in low and medium-priced cars. It is hard to understand why the engine referred to has any bearing on the matter of valve arrangement, as Mr. Woolson infers.

Mr. Woolson apparently believes that almost all advertising departments are proverbial liars on gasoline mileage. He says that I show still better results, namely 50 miles per gal., but at a sacrifice of good performance. There is not one fair-minded capable engineer who will not agree with me relative to the ideal mileage possible as shown in Fig. 33 of my paper, under the conditions set forth. Furthermore, we do not have to use engines that knock badly. If Mr. Woolson had looked more carefully into my paper, he would have found increases in economies over twice as great as what he cites as possible at ordinary driving speed. In the test shown in Fig. 23 of my paper, we get 1.125 lb. of gasoline per b.hp-hr. at 28.6 m.p.h. Mr. Woolson places stress on this figure and contends that by proper carburetion it is possible to make this 0.93 lb. per b.-hp-hr., representing a gain of 20 per cent. However, I also show, in Fig. 27, results slightly better than 0.93 lb. per b.hp-hr., and in Fig. 26 at this same car speed we get 0.75 lb. per b.hp-hr. This is a 24-per cent increase in gasoline mileage over what Mr. Woolson claims proper carburetion will give. For the cases cited above, the carbureter had relatively very little to do with the results obtained. I will mention a little later the results obtained so far as the carbureter is concerned.

I am sorry that Mr. Woolson looked for conclusive evidence in my paper with regard to whether the proper amount of heat was furnished under average driving conditions. He should read the second paragraph of my paper more carefully. The result of the tests shown in Fig. 28 indicate that the vaporization at partial loads was not really bad at least; also, the indicated thermal efficiencies of the tests in Figs. 26 and 27 are not bad. Mr. Horning points out that the results come within his expectations, after a study covering fundamentals which were not treated in my paper. The results, although not perfect, are found to be fairly good. To go into the details of making the results possible is beyond the scope of my paper. As to whether the mixture was over-rich when accelerating with the engine cold, the mixture used

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for this open-throttle condition was one which gave a gasoline consumption of less than 0.52 lb. per b.hp-hr. Comparing this with the results of our best aviation engines, which do not carry fan and battery-charging loads, it appears that an over-rich mixture was not used in tests without an accelerating pump. Mr. Woolson admits that he found recently that higher temperatures give better results. He will find that there is still further room for improvement, and also that there are new devices which have considerable merit.

Mr. Woolson pleads for the acceptance of my statements regarding the aluminum piston, with reservations. During the war I was in the gun business for the Government. We learned that we could accomplish what we went after. It required hard work, but I think we demonstrated to all our Allies that we could shoot more accurately than they could when it came to mixing bullets and propeller blades. In view of those records, I will trust to having the statements I made relative to the aluminum piston accepted without any reservations whatsoever until the results claimed can be verified by personal observation.

There is one matter in connection with these tests in regard to which I do not wish to be misunderstood. A case in point is Mr. Woolson's remarks relative to the improvements that can be made in performance at a few fixed car-speeds and concerning additional tests that are desirable to make the investigation more complete. The latter had to be omitted from the paper for brevity's sake; also, the time for conducting the tests was very limited. The first test was run on Dec. 18, 1920, and the last one on Dec. 28. The results show clearly what can be done with one carbureter setting over a range of speeds from 10 to 60 m.p.h. and at wide-open throttle for speeds from 400 to 3200 r.p.m. The results that it is possible to attain under ordinary limits and with diligent care are far in advance of those given in the paper. The thing to remember is the wide range of conditions that were met with one carbureter setting. The ultra results at a few speeds are comparatively easy to obtain.

C. P. GRIMES:—Much credit is due Mr. Nelson for the presentation of so admirable a paper prepared with his definite point of view always in mind. About the time the war started, Mr. Nelson investigated guns and was able to develop a cam, used in the Nelson gun control, that far exceeded any of those developed by men who had

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spent years in the gun business. I think sometimes we work in one line and do not go far enough to get a real perspective of what we are trying to do.

I am most interested in general car performance. I observe from the paper that throughout the general driving range of from 20 to 40 m.p.h. we are using only from 17 to 43 per cent of the power available at these engine speeds and are consuming from 2½ to 1½ times more fuel per horsepower-hour than we would use in the same engine if it were allowed to run full-open. A satisfactory overgear would increase the efficiency of the powerplant.

The proper location and timing of the spark is important. With a uniform car-speed of 20 m.p.h., I noted an increase in miles per gallon for each of the following spark-settings: 10, 20, 30 and 40-deg. advance. The spark location and timing is a function of the actual compression, so that in no case should the timing for full-open throttle be expected to act efficiently for the part-throttle condition of ordinary driving. I should consider Mr. Nelson's method of obtaining the road condition horsepower to be too cumbersome and inconvenient for practical use. It is to be presumed, however, that he exercised the same care in the timing of the spark as in the case of the throttle adjustment.

I have found it convenient for road testing to drive a wood plug into the starting-crank hole, attach a metal pointer set at zero when No. 1 cylinder is at top firing center and adjust the end of pointer about ⅛ in. from a flat surface upon which I could scratch the 10-deg. marks. Then with the engine running and the rear wheels jacked up, I could read the miles per hour and the location of the spark by holding the wire that formerly went to the No. 1 spark-plug onto the metal pointer.

I have proved to my entire satisfaction that a change of 5 deg. in the timing of the spark is noticeable in a road test and often is the determining factor when climbing our test hill.

My method of road testing is based entirely upon the speedometer, a stop-watch and the weight of the car in question. Force is defined as the rate of change of momentum with the time, upon which definition this work is based. Consider a vehicle coasting from 40 to 30 m.p.h. At the former speed the vehicle has stored within it energy or the capacity to do work expressed as momentum or Mv. At 30 m.p.h. the vehicle has mo-

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mentum, but of a lesser value. In other words, the vehicle has dissipated a portion of its energy during the time t required for it to coast on a level pavement from 40 m.p.h. down to 30. On a quiet day with no wind blowing this energy will be consumed in overcoming the friction of the vehicle to motion, called rolling resistance. Then we may write:

$$F = (Mv_1 - Mv) \div t = \text{Rolling Resistance}$$

Light weight is the deciding factor in acceleration and tire cost, but, since wind-resistance is the predominating factor at touring speeds, the question of economy is readily reduced to a condition similar to that of the airplane in which 1 lb. of head-resistance is equivalent to 15 or 20 lb. of dead-weight.

The Franklin touring-car has been analyzed as follows:

Speed, m.p.h.	10	20	30	40
Power to Roll Car, hp.	1.22	3.49	7.82	12.36
Percentage Used To Overcome Wind-Resistance	14.50	40.00	60.00	70.00

This leads me to suggest that body designers will some day be compelled to recognize this resistance and work for its reduction.

In regard to manifold and cylinder-head temperatures, I believe that just sufficient heat should be applied to the fuel in the hot-spot to prevent wall-flow; in other words, to prevent unequal distribution without resorting to excessive manifold velocities. Maximum economy will then be obtained with a combustion-chamber wall temperature just under the preignition point. In our case this comes at from 550 to 600 deg. fahr. By the use of excess cooling, I can reduce this temperature to 225 deg. fahr. at the sacrifice of both economy and acceleration.

In closing I would point out that maximum economy does not come at either maximum torque or the leanest gasoline-setting at which you can make the car run and accelerate.

MR. NELSON:—Mr. Grimes' method of studying car performance is indeed interesting, particularly the method of determining the load factor. This is a quick and ready means of getting approximate results. My experience with speedometers has, however, been very unsatisfactory. The inertia effects of certain parts are so marked in some types of instrument that I would never think of using them to determine car acceleration. When the car acceleration is increasing, the speedometer lags; and when the acceleration is decreasing, the speed-

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ometer runs ahead of the true reading. Driving a high-grade car I pulled out the reset while the car was standing. After doing this, the speedometer quickly showed 20 m.p.h. and, of course, soon showed zero again. An instrument which is so sensitive to shock certainly cannot be used in laboratory work. These remarks necessarily do not apply to all types of speedometer, but if care is not used to select the type of instrument most suitable for testing purposes, the results will be very questionable.

In reference to the spark location used in the tests, only one setting was used. The automatic advance took care of the spark location. Our experience has been that, with a proper quality of mixture, the spark-advance is not nearly so important as when the mixture is slightly wrong. In checking the results as mentioned by Mr. Grimes, we have found almost invariably that the quality of the mixture was wrong. This may vary with different engines and Mr. Grimes' suggestion is worthy of careful attention.

HERBERT CHASE:—Mr. Nelson has hit upon a point which few others have emphasized, namely, the necessity of getting better economy under the part-load conditions that obtain in the average passenger-car, particularly, during a very large percentage of the time of operation. Testing is done at full load almost entirely and few engineers give the consideration that they should give to the matter of load factor mentioned by Mr. Grimes.

Mr. Nelson has shown one way in which it is possible to increase the fuel economy at part load. and it is a subject deserving of further consideration. There are other methods of accomplishing the same thing. One is to build a constant-compression engine. I mean an engine of conventional type that is a constant-volume engine, but which has constant compression at all loads. This has been done in England by Mr. Ricardo. Others in this country have experimented with the same thing. I know one engineer who has a six-cylinder car of about average size on the road today, with which he claims to be getting close to 60 miles per gal. Such a performance, if it can be realized commercially, would constitute a long step in advance. The method in this particular case is always to take into the cylinder practically the same amount of air, controlling the amount of fuel in proportion to the load demand. The rich mixture that is taken in through one additional valve is, to a certain extent, localized in a portion of the combustion-chamber adjacent to the spark-

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plug. Then there is always an excess of air under part-load conditions. At wide-open throttle, there is simply enough air to burn the entire charge. That is one way of getting this desirable economy at part load. There are other methods. Variable valve-timing will help. Mr. Sargent has presented papers before the Society in which that has been the theme, but it is a matter that should be given further and more thorough study than it has received to date. We have done much in the way of adding accessories, hot-spots and what not, all of which are commendable and have produced some increase in economy, but we must, if we can, get rid of the basic thing which causes lack of economy, namely, throttling of the Conventional type.

EDWARD D. THURSTON, JR.:—In connection with Mr. Fielder's work, Fig. 2 of his paper shows the results of a test as to the saving in fuel consumption and increase in horsepower obtained as a result of using the thermostatic control. Also, in Table 1, he presents an economy test which gives the power developed, the fuel consumed and the manifold temperature. The changes are rather small and I ask Mr. Fielder if the ratio of fuel was precisely the same under the two conditions; that is, whether the carbureter was readjusted to have the same ratio of fuel. Very little variation in the carbureter setting or very little change in the mixture would account for a difference of only 0.04 lb. per hp.

In connection with Mr. Howard's paper, he speaks of determining the vapor-pressure of gasoline by introducing a certain amount of it into a barometer tube, the increase in pressure being the partial pressure of the gasoline. That seems to me to be perfectly practicable in the case of a simple liquid, or, if a small amount of gasoline is placed in a tube, the pressure will surely rise a certain amount; but I have found by experience that it makes a great difference how much gasoline is put in. If we introduce 2 or 3 cc. of gasoline, we may find a pressure-increase of 2 or 3 in. of mercury; if we put in 5 cc. of gasoline, there may be twice that amount of pressure-increase. What is the vapor rating of a gasoline? Is it the first reading or the second? I do not understand yet how we are to get the vapor-pressure of gasoline.

In connection with the cooling or the drop of temperature in the inlet-manifold, that introduces an interesting point in regard to measuring the temperature in

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the manifold. This has been brought rather forcefully to my attention in the last few weeks because I have been doing some work along this same line. In some cases at least the apparent temperature-drop through the carbureter is greater than could be accounted for by the evaporation of all of the fuel. In other words, if we evaporated the entire pound of fuel, we would have but 130 heat units available, while the fall in temperature of the air times the specific heat times its weight is greater than 130. Obviously, something is wrong. Mr. Howard's paper has given me a clue to the explanation. The mixture is probably still wet, some of the unvaporized fuel has become lodged upon the temperature-recording device and, by its evaporation, has given us a false reading of the mixture temperature. I cannot see that this will be very different with different types of measuring instrument. Whether we use the thermocouple or the thermometer, the result will be about the same and that rather leads us to suspect that some of the manifold temperatures we are recording are not the average or correct temperatures; that they are too low, on account of vaporizing some fuel on the temperature-recording element.

R. E. FIELDER:—No attempt was made to keep the ratio of fuel to air precisely the same. Conditions, physically, were kept the same as nearly as possible throughout all comparative tests; the magneto timing and the carbureter setting remained the same.

J. D. GILL:—For the past several years, as a refiner and marketer of gasoline, I have heard many complaints about commercial gasoline. For the past three years I have attended the Society meetings, particularly the fuel sessions, in the hope that I might find out just what the automotive engineering profession wants for engine fuel. Perhaps the petroleum refiners could not provide just what is wanted, because immense quantities of engine fuel are being demanded, but the refiners do wish to know at least what is desired and having this information would try to live up to such broad specifications as might be determined.

I have not seen any direct comparisons of different kinds of engine fuel, with respect to either accelerating power or fuel economy. The conclusion I have reached after letting my mind run over the many accessories that have been added to the car to assist carburetion, vaporization and the like, and the many fuel experiments

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that have been performed, is that, if certain things are done, such as the installing of hot-spots, satisfactory results will be obtained with the present-day commercial grade of gasoline.

Two outstanding factors have been mentioned repeatedly in connection with the burning or utilization of engine fuel. One is that, under certain conditions, knocking ensues; the other is that an undesirable dilution of crankcase oil results from the use of present-day fuels. In Mr. Howard's paper it was shown that, under proper conditions, fuel taken into the system is perfectly volatilized and remains a dry gas. This is the condition that was sought to eliminate the dilution of crankcase oil. The statements made by Mr. Howard were confirmed by the experiments described by Dr. Dickinson, in which the vapor-tension of practically all the components of gasoline which he examined was below the corresponding values on the adiabatic curves, showing that the material would remain dry at the ordinary compression pressures in the cylinder.

Keeping these things in mind, but passing to one of the other factors for a moment, we have seen also that knocking results with lean mixtures in the cylinders. In the present-day engine, having a long manifold system, there is no doubt that the distribution of the fuel is not uniform and that different cylinders receive different quantities of the power supply. May it not then be that some of this knocking which we have been talking about is not at all due to the character of the fuel itself, but to the lack of the fuel in proper quantity at some certain cylinder? I repeat that all that has been said indicates that if "certain things" are done, the gasoline that we are using today will give satisfactory results.

However, we can accomplish our purpose most readily by utilizing the physical characteristics of gasoline cited by Mr. Howard. If in a water system that has a reciprocating pumping unit we desire a continuous flow of water, we put into the system somewhere between the pumping cylinder and the delivery point a reservoir, so that the pulsations of the pump are lost in the large volume of the reservoir and the flow of liquid is continuous. That is about what we desire, it seems to me, in an internal-combustion engine. Reverting again to Mr. Howard's statements and their confirmation by Dr. Dickinson, we find that we can make a perfectly dry mixture and that it will stay dry without the application

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of heat; but time is required for this complete volatilization of the fuel.

Suppose we were to put into the system, somewhere between the carbureter and the place where the fuel mixture enters the cylinder, just such a reservoir in which the "pulsations" from the carbureter would be thoroughly mixed with the air and given time for vaporization. Suppose also that the mixture which finally passed out of this reservoir was in conformity with Mr. Howard's idea of a dry complete mixture of somewhat under 2 per cent of fuel mixed with air. Would we then have the knocking which comes from poorly fed cylinders in the system, and would we have the excessive crankcase dilution which has been a source of very great annoyance within the last few years?

I feel that perhaps some of the criticism which arises from crankcase dilution may not be justified solely by any increase in dilution that we now experience; we are inquiring much more closely into performance today than we did years ago. Crankcase dilution, of course, always existed, but perhaps we can agree that it has been excessive. Can we not improve conditions by making the mixture complete and dry, not by using the hot-spot or other means which have been placed on the market, but simply by giving the fuel sufficient time in which to vaporize completely and mix with the air before it passes into the cylinders?

PRESIDENT J. G. VINCENT:—We should not overlook the fact that the average car is working much of the time under conditions that are not ideal. The automobile is used to a great extent for business now, and many trips in cold weather are just to the house, the store or the office. In many cases such trips do not occupy more than 10 to 15 min. of time in very cold weather. We ought not to conclude that all these devices perform as well as they should under such circumstances.

F. C. MOCK:—In our organization we are not sure that the volatility of a mixture of a series of elements can be determined by separate measurements of the volatility of each element. Some years ago we seemed to find that when 56 to 58-deg. Baumé Mid-West gasoline was introduced into about 15 times its weight of air at atmospheric pressure, only about 30 per cent of the gasoline would evaporate in an indefinite length of time. A fan circulation was used to avoid local segregation of the vapor. We did not follow through the method described

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by Mr. Howard of determining by fractional divisions the amount that should evaporate, but I am sure that this method of computation would have shown a much greater percentage of evaporation. I have read that a certain French physicist seemed to find a condition of mutual saturation existing between closely related elements such as these, and this may be the reason for the discrepancy. To present the results of our experiments in more striking form, I would say that they indicated that if an amount of gasoline sufficient to "carburet" the air in the hall in which this meeting is being held were kept in open vessels, or spilled upon the floor, it would be perfectly safe for persons to light matches and smoke, provided open flame was not brought into contact with any liquid gasoline. I have not tried this.

I note that one of Mr. Howard's illustrations is based on a pressure in the engine manifold of 0.5 atmosphere, which would be equivalent to that of about 14¼ in. of mercury. We practically never have any trouble with vaporization at this vacuum and, under nearly all conditions of our observation, the manifold is substantially dry in such a vacuum. Where we have our trouble is at wide-open throttle, when the manifold pressure is nearly that of a full atmosphere.

One rather remarkable thing is that we apparently find that many engines show just as good power and fuel efficiency with the gasoline feeding to the cylinders as a stream along the walls of the manifold, as when the fuel is converted into a mist with a "hot-spot," under conditions of steady load and air speeds above 60 ft. per sec. *Cold manifolds fail under changes of speed and load,* and at temporary periods of driving where the air velocity falls below the limit already mentioned. We do find considerably less carbon deposit when the fuel goes to the cylinders in the form of a mist.

GEORGE M. BROWN:—So far as Mr. Howard's paper concerns the evaporation of fuel, I believe that it is very nearly correct. This opinion is based on more than seven years of experimental work in the interest of fuel efficiency. This time was spent entirely on the road, in traveling close to 100,000 miles under all conditions. I note no very appreciable difference in the evaporation possibilities of fuel today from that of 10 years ago, under my principles of usage.

Mr. Howard gives an equation representing evaporation in terms of time, surface and heat. To this he should

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have added what I might call "dispersion." Elementary physics teaches us that this is the effect of wind on evaporation, insuring an equalization of the vapor content per cubic inch of air, or an equal degree of saturation. My experiments have been based on the primary principle of a very large surface and very rapid dispersion which produces an effective evaporation and thoroughly equalized mixtures. This condition is attained through the carbureter instead of the manifold, thus insuring a mixture of equal richness in each cylinder, and depending simply on manifold design against wire-drawing in any particular cylinder, to prevent an inequality in volume.

From my long experience I believe that the solution of the fuel problem is based on surface and dispersion at initial contact, which is turbulence in the carbureter. My practical tests have proved that every possible benefit can accrue from this condition, as to both fuel economy and engine efficiency, with the minimum of complications.

In his answer to the fuel questionnaire, Mr. Horning states that he is studying turbulence as the most effective factor. After a close study of the application of turbulence in both ways, I do not know that it makes a great difference whether we start or end with this idea; but to start with it gets results by a simpler method and I believe that this reduces distribution difficulties. The two reports from Mr. Howard and Mr. Horning appear to be of marked value from a practical standpoint.

FRANK A. HOWARD:—In regard to the questions that were asked on the vapor-tension of gasoline, it is quite true that the more gasoline there is the higher the vapor-tension will be, within limits. The method by which that is met is to take the maximum vapor-tension which can be obtained with a sample of adequate size and continue to add gasoline so long as the pressure shows any increase. In the case of the original gasoline, that is a very difficult matter because there is a small quantity of dissolved permanent gas in it. I suppose, if enough gasoline were added, the pressure could run up to equal that of one atmosphere. That criticism does not apply to vapor-tension determinations or distillation residues. That last 10 per cent can be regarded as a very nearly homogeneous compound. There is another way of checking it which is very good. The chemically pure hydrocarbons in the gasoline can be isolated and vapor-temperature determinations made of them.

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As to the measurement of manifold temperatures, that wet-bulb thermometer effect is bothering many engineers. In my reference to manifold temperature I was talking about a dry mixture. I have no idea how to obtain a true indication on a wet mixture.

I said I did not know of any way of increasing the time element for vaporization. Mr. Nelson has already found a way for increasing it. This shows what the progress in respect to hot-spot design is and what is possible in the way of juggling the three factors of surface, time and heat. Apparently we can handle all three of them now. None of them is excluded.

Mr. Brown raises the point that, in addition to the factors of time, surface and heat, the element of "dispersion" enters into volatilization. This is correct in the sense that the dispersion of the fuel vapors in the air must be great enough to give substantially a homogeneous mixture if the full inherent volatility of the fuel is to be utilized. It is theoretically possible that stratification or lack of homogeneity either in the intake pipe or in the engine cylinder might give the condition of a saturated stratum of air into which the fuel could no longer vaporize, and above this an unsaturated stratum. While the average volumetric content of fuel vapors in the charge would, therefore, be below the partial pressure of the fuel at that temperature, vaporization would be arrested until the process of diffusion equalized matters. True gaseous diffusion is, in itself, probably much too slow a process to be of value in carburetion and, while this is theoretically covered by the time element, turbulence therefore enters as a necessary practical factor for the utilization of full inherent volatility. This is not, of course, limited to cylinder turbulence, but includes turbulence in the carbureter and manifold as well.

President Vincent has directed our attention to the fact that the starting or warming-up problem is a very serious one which is often overlooked in discussions of the vaporization of fuel. There are many promising mechanical solutions of this trouble and I have no doubt these will be developed to meet perfectly the requirements for engines to be built in the future. With regard to existing engines, however, very little seems to have been done to help out on this matter. We have attacked it from the fuel standpoint by marketing at retail, with such wide distribution that we hope practically all motorists will be reached, a special high-volatility fuel which

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can be called a petroleum ether. The value of such a product for priming is, of course, well recognized. This particular product is so highly volatile that it readily forms an explosive mixture at a temperature as low as 72 deg. fahr. below zero, which is as low a temperature as we have been able to obtain in our own laboratories. There is being marketed with this priming ether a priming-cup, which can be mounted on the dash. This cup is in reality an elementary carbureter, having an air passage into which the priming ether is sprayed from a calibrated jet orifice. The capacity of the cup is sufficient to run an ordinary engine for about 35 sec. The device is operated as follows. The engine is started and run for about 500 revolutions on a fuel so volatile that low air and engine temperatures have no effect. This running period is long enough to warm the engine up fairly well. Of course, the better the hot-spot or heating device is, the more perfectly normal intake-pipe conditions will be established within this time. It is found in practice that this device can be operated without any particular skill. The regular throttle-valve is merely set in the idling position, the priming-cup filled and the engine started in the ordinary way, the choker-valve being wide-open. The richness of the mixture supplied by the primer is such that the dilution with air through the crack in the throttle-valve does not reduce it below firing proportions. Before the cup is exhausted, the engine will usually be warm enough so that the throttle can be opened fairly wide and the regular carbureter will come into operation without the use of the choker-valve. Here again the leakage of air through the priming device is so small, with the throttle appreciably open, that the regular mixture of the carbureter is not reduced below explosive proportions. The primer, therefore, need not be shut off at the exact moment when its charge is exhausted, but should, of course, be shut off before the throttle is closed again.

This method of meeting the difficulty which President Vincent mentions has obvious disadvantages, but it does seem to afford a cheap and simple means for the ordinary motorist to obviate winter-starting and warming-up troubles.

A. C. FIELDNER:—It is truly astonishing that more attention is not paid to the composition of automobile exhaust-gases. I believe it would promote gasoline economy if manufacturers would install a gas-sampling con-

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nection in the exhaust pipe, between the muffler and the engine, and bring it up to some convenient place on the vehicle where a gas sample could be taken at any time. It certainly would pay large trucking companies to employ a chemist who would analyze the exhaust gas on motor trucks for the purpose of checking up carbureter adjustment.

MR. CHASE:—I have been very much interested in Mr. Fieldner's paper because on behalf of the Society I had something to do with suggesting the nature of the tests described. When the matter was broached several months agao, we placed particular emphasis on the desirability of conducting the tests under the actual conditions of service. I expected that the results would show exactly what they have shown; that the average car today is wasting, due to incomplete combustion, at least 25 per cent of the fuel that is fed through the carbureter. Not only does the engine run under the inherently inefficient condition imposed by throttling, but only 70 per cent of the total fuel fed is burnt. We sometimes criticize, with more or less justice, the oil companies for the quality of fuel that they furnish, but when a condition such as the one that has been shown by this paper to exist is present, it is certainly evident that there is much to be done by the automotive engineers and manufacturers as well as by the fuel producers.

FLAME MOVEMENT

C. A. FRENCH:—In the experiments described acetylene, sulphuric ether and carbon bisulphide were exploded in a closed cylinder of fixed volume. A glass window, running the entire length of the cylinder, was used to permit the making of photographs of the flame as it passed through the cylinder after having been ignited at one end. Such experiments are of great scientific interest and value, and these gentlemen should receive all possible encouragement to continue the work, particularly as combustion research has always been at a low ebb in this country. We should not, however, take these preliminary results as being necessarily indicative of anything that happens in the cylinder of an engine burning kerosene or gasoline, for the reason that the fuels used in the experiments are incapable of burning like paraffin hydrocarbons.

The first prerequisite of an unobjectionable flame for internal-combustion engines is that it be so blue, non-luminous, non-radiant and of such low actinic power, so

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that it is extremely difficult to photograph in the time interval available. Moreover, all of its characteristics are radically different from those of any luminous flame. In attempts to find the causes of our trouble with kerosene and gasoline, countless experiments in flame propagation, ignition temperatures and the like have been made, but in 99 out of 100 cases other fuels than kerosene and gasoline have been used, the conditions under which kerosene and gasoline are burned were not stimulated, and the results obtained, while of scientific value, have not helped us materially in our problems.

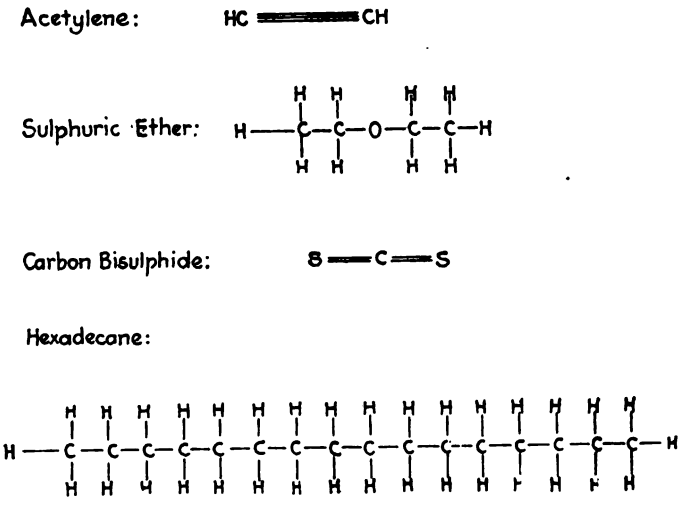

FIG. 7—GRAPHIC COMPARISON OF THE CHEMICAL COMPOSITION OF VARIOUS SUBSTANCES

A comparison of acetylene, sulphuric ether and carbon bisulphide with hydrocarbons of the paraffin series shows a great difference in their structure, compositions and characteristics. The ethanes, of which acetylene is the first member, have an empirical formula $C_n H_{2n-2}$ and all are unstable, unsaturated hydrocarbons. Acetylene gas has about the same weight as air; hence it diffuses slowly. In the formation of unsaturated hydrocarbons some of the carbon atoms, not being able to secure all of the hydrogen they would like to have, are compelled to form double, or sometimes triple, bonds with each other. Carbon atoms are always very reluctant to form these double or triple linkages between each other, it being necessary

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always to supply energy to force such a union. When these substances burn, they give off more heat than is indicated by the amount of carbon and hydrogen they contain. Such compounds are endothermic, that is, formed with a disappearance of heat, which is given off again when they dissociate. In the case of acetylene, this excess heat is about 23 per cent. Highly endothermic compounds of this kind are always unstable and may dissociate with explosive violence in the entire absence of air, oxygen or any other supporter of combustion. Under that condition, Berthelot and Vielle dissociated acetylene with a resulting pressure of 5638 atmospheres, after which the carbon was left as a solid lump with a brilliant surface. Explosive dissociation of compressed acetylene so frequently occurs spontaneously that all civilized countries prohibit its shipment or storage under pressure of more than 1 atmosphere, unless dissolved in acetone, or other solvent, and the solvent absorbed in a porous solid.

Except when used in special burners, it produces soot with mixtures of any ignitable proportions whether burned explosively or otherwise. The blue-flame period of acetylene burned explosively is extremely short and complete dissociation with more or less violence occurs at an early period, causing a halt in the oxidation, after which the free carbon and free hydrogen may or may not burn, according to circumstances. It is decomposed readily by heat, when it may completely dissociate, or it may polymerize into any one of a vast number of organic compounds. Thus we see that it is a highly endothermic, unstable gas, the flame characteristics of which are, except under most unusual circumstances, very different from those of the paraffin hydrocarbons.

Sulphuric or diethyl ether consists of an ethyl radical on each side of an oxygen atom; while the bonds of carbon to oxygen can be said to be fairly strong, nevertheless compounds containing them are often very reactive. Ether vapor allowed to flow through an expanding nozzle into an exhausted tube, 4 to 6 ft. long, turns its kinetic energy into heat on reaching the end of the tube and dissociates with considerable explosive violence. Any of the organic molecules having two similar radicals, bonded between them to an O, or to a ketonic oxygen, CO, are prone to have unusual properties; the vapor-tension of ether is characteristic of one of its radicals instead of the whole molecule, showing that the two radicals do not join forces to any considerable extent. This tendency of the

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radicals to act independently, that is characteristic of the ethers and at least some of the ketones, shows an anomalous bond that should warn us that these substances would, under certain circumstances, dissociate with considerable emphasis. We should expect about the same sort of a ragged pressure-line from the explosive combustion of ethers and some of the ketones that we get from the dissociation of the highly endothermic fuels.

The paraffin or saturated series of hydrocarbons have the empirical formula $C_n H_{2n+2}$. Their heat of formation being positive they are not under any stress and are therefore stable. From methane, CH_4, the first member, up to and including pentane, C_5H_{12}, all members of the series could probably be burned explosively under as high compression as we would care to use in automotive engines, and they would never produce detonation or other objectionable effects, unless an excess were used. All periods of their flames would have a transparent blue color. At least it seems certain that neither detonation nor luminous flame could be produced in a homogeneous stoichiometrical mixture of air and paraffin series molecules, no molecules of which contained more than 12 atoms. Such a mixture should burn under any pressure or at any velocity with no undesirable effects. A stable hydrocarbon molecule of not more than 12 atoms has all of its atoms on the outside, or at least in communication with the outside, so that throughout combustion every fuel atom is being bombarded with oxygen molecules and atoms enough to burn them; under such circumstances oxidation will always take precedence over dissociation. There is no experimental evidence to show that detonation or knocking has ever occurred in an entirely blue flame of a paraffin hydrocarbon, or in ring compounds of not more than 12 atoms.

With a molecule as large as hexadecane, $C_{16}H_{34}$, the largest molecule usually found in kerosene, its size prevents more than 37 of its atoms having contact with oxygen; therefore the 13 inside atoms must wait for oxygen until the outer layer is burned away. If this burning takes place too rapidly, the oxygen cannot secure contact with the inside atoms of the fuel molecule until too late to save them from cracking. In all reason we would expect the 13 atoms of C_4H_9 to be the end of the chain. As no such compound can exist, it would crack in the characteristic manner of the saturated series into one saturated and one unsaturated compound, which

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in this case would be ethane, C_2H_6 and acetylene, C_2H_2 and one lone hydrogen atom.

We should expect this kind of a combustion to halt when the 37 outside atoms were burned. The cracking and the formation of the acetylene would absorb some heat, and the acetylene would then dissociate with explosive violence; after this the free carbon, free hydrogen and the ethane would burn, making two and possibly three pressure peaks on the diagram. The flame begins blue, *as do the flames of all hydrocarbons,* and stays blue until the 37 atoms are burned away, after which it becomes brightly luminous, radiant and actinic. Practically always, an excess of fuel is followed by dissociation, even with small fuel molecules. A dissociation is always productive of the mixture. While a reasonable amount of ionization is necessary and desirable in combustion, an excessive amount can and does produce effects that are most undesirable. A luminous flame always denotes excessive dissociation.

It is important to remember that any kind of a flame of a common liquid hydrocarbon fuel cannot be propagated without an initial area or period of transparent blue flame in which the fuel and air are in explosive proportions. Entirely green, lavender, red, yellow or white flames cannot be propagated, nor can they be maintained if too widely separated from the blue flame. If a yellow flame is examined through a yellow color screen, it will be found to be permeated by a thin blue flame and, if a supporting atmosphere is available, the yellow spot will be found to be entirely surrounded by blue flame. This is true also of flame spots of green, red and white, when each is examined through the proper color screen. In stable fuels green, red, yellow or white flame spots can be said to be the result of either temporary or permanent lack of oxygen. Thus, it appears that a transparent blue or lavender flame always indicates oxidation, while spots of any other color indicate either excessive cracking into new, smaller hydrocarbons, and the large production of CO, or the complete dissociation into free carbon and free hydrogen.

It will be found that if a given quantity of stable fuel is burned with an entirely blue flame, the flame occupies less space than when spots of any other color appear, provided too great an excess of air is not used. When a combustible mixture is of correct fuel-to-air ratio and the fuel is in the proper physical state, the resulting blue-

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flame combustion is much simpler, more complete and compact than any other. There is much evidence that carbon always burns immediately to CO_2, when it can secure the necessary air. In any event a normal blue-flame combustion will go to completion in less time and space than any other, thereby imparting all of its molecular forces to the gases early in the stroke and allowing a more complete expansion than is common.

It would not show any flame at the exhaust port. Only about 8 per cent of its energy is in the form of radiant heat, against 30 per cent or more in the luminous flame; it is incapable of making soot; and its progress is not affected seriously by contact with cold surfaces. As radiant heat has the same velocity as light, it is nearly a 100-per cent loss in an engine cylinder; therefore it is the imperative duty of combustion engineers to devise a method by which present fuels can be burned with a blue flame.

Messrs. Woodbury, Lewis and Canby introduce experimental evidence which they believe shows autoignition of parts of the mixture ahead of the flame-front, which, under certain circumstances, is certainly possible. In the burning of rich mixtures of stable fuels and in the burning of unstable fuels in any fuel-to-air ratio, there is a great amount of dissociation from which an abundance of charged ions of every constituent of the mixture is produced. A pressure wave probably cannot be made to travel through molecular air in excess of the velocity of sound; however, there is nothing that prevents charged ions from greatly exceeding that rate. As spontaneous combustion can be started far below the ordinary ignition temperature of the fuel with oxygen ions and in many cases with hydrogen ions, there is no good reason for doubting that much of the so-called detonation or knocking arises from ignition of remote parts of the mixture by charged ions produced in the dissociation of the fuel. A reasonable degree of ionization of oxygen is of benefit in any combustion, but it should take place before combustion begins, as a sudden large production of ions during an explosive combustion is certain to produce undesirable results. This is another valid reason for the study and development of the blue flame in which dissociation is not a necessary event.

WILLIAM C. DAVIDS:—Has Mr. Fielder ever tried to heat the air between the carbureter and the engine, instead of heating it before it goes through the carbureter?

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I have found in practice that heating the air after the gas comes through the carbureter is far better than heating it before. Some years ago I experimented with hot-spots and used them in two-cycle engines carrying the hot-spot under the manifold and so heating it completely across. That heated the air and gas after it left the carbureter, and I think that is the proper way to apply the heat. The gas passing down into the crankcase of the two-cycle engine and receiving its heat from the pistons was satisfactorily vaporized and we obtained exceptional efficiency from the engine.

MR. FIELDER:—We believe that heating the air between the carbureter and engine by the hot-spot method is undesirable because the temperature is uncontrollable due to the variations in the atmospheric temperature at different seasons of the year. This is a condition that we have tried to overcome. We all know that there are certain periods during the year when the average internal-combustion engine functions best, which is due to the atmospheric temperature being right, and we have tried to standardize this temperature throughout the year by use of the thermostat.

MR. SPERRY:—The fact is interesting that in the Diesel engine there is never any carbon monoxide to be found. I thought possibly that this might be a peculiarity of some work that we are doing and so sent our chemist to a Navy Yard where they are running Diesel engines of different sizes up to 700 hp. to analyze samples of exhaust gases. We now have analyzed many samples from engines running at 25, 50, 75 and 100 per cent of their rated load, and at 10-per cent overload. In none of those samples do we find the slightest trace of carbon monoxide. There is evidently some fuel saving there. In following out Mr. Chase's suggestion, if we are to compress the air, why not go somewhat further and produce auto-ignition, eliminating carbon monoxide entirely and at the same time rendering available a wide range of fuel and much cheaper fuel than gasoline.

I find that many engineers are afraid of high compression in an internal-combustion engine. Is it understood that, with the two or three rings that it seems wise to some engineers to add to get 500-lb. instead of 65-lb. compression, the piston will drop right through the cylinder of its own weight. There is no extra friction that amounts to anything and those pistons are coming out of long runs practically as good as when they started.

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Diesel engines are perfectly practical. There are thousands of them in operation. I venture to say that before this Hudson Vehicular Tunnel is complete we will have no carbon monoxide to cope with.

W. M. WALLACE:—I am indebted to Mr. Nelson for bringing to my attention the details of the results of his experiments with constant and variable-clearance aluminum pistons. The results of my own research to date, regarding this subject, indicate that the troubles with pistons are due basically to leakage around and under the rings and to lubrication difficulties. I doubt that joint leakage amounts to very much, compared with the leakage around and under the rings. Lubrication difficulties are accentuated in many instances by the apparent failure of designers to pay proper attention to the design insofar as lateral or wall pressures are concerned. There are also many other detail points, but these are not so important.

It is obvious that pistons should be as simple as is possible. The piston material preferably should have the same coefficient of expansion as, or less than, that of the cylinder material. Other views of the problem in certain cases, as in air service and in tractor and marine requirements where large and constant power is needed, indicate the necessity for some material capable of transmitting the heat quickly. To accomplish this alloys of aluminum usually are resorted to.

It seems that a false head of aluminum might be substituted for the more-or-less complicated and certainly more expensive type suggested by Mr. Nelson. It appears possible to attach such a false head by a single adequate fastening at its center, thus allowing the material to change form without distorting the light cast-iron shell, as is indicated for Type *U*, Fig. 9. With this exception the sketches shown in Figs. 8 and 9 are all taken at random from actual pistons of American-made engines. Some are old; some are more recent. They were assembled to show, so far as is practicable, the trend of practice regarding the provision for side-pressure. To make comparisons it was necessary to make a few assumptions, as follows:

(1) The thin surfaces above the bottom ring are neglected as bearing surfaces. This in most cases is certainly a fair assumption
(2) The material is considered rigid and not bending

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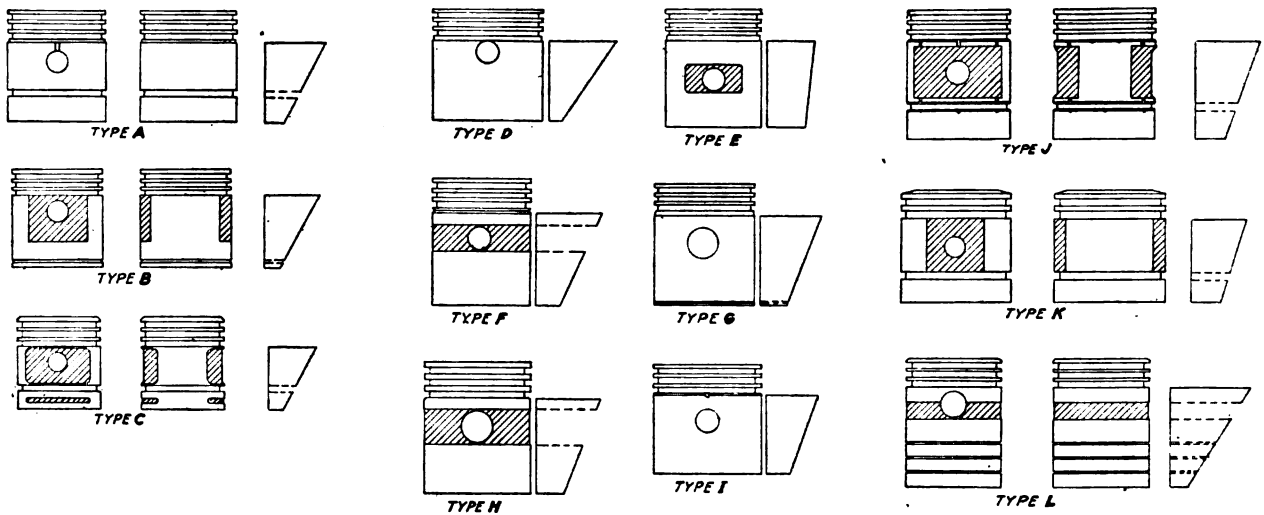

FIG. 8—SOME OF THE VARIOUS TYPES OF PISTON USED IN AMERICAN ENGINES

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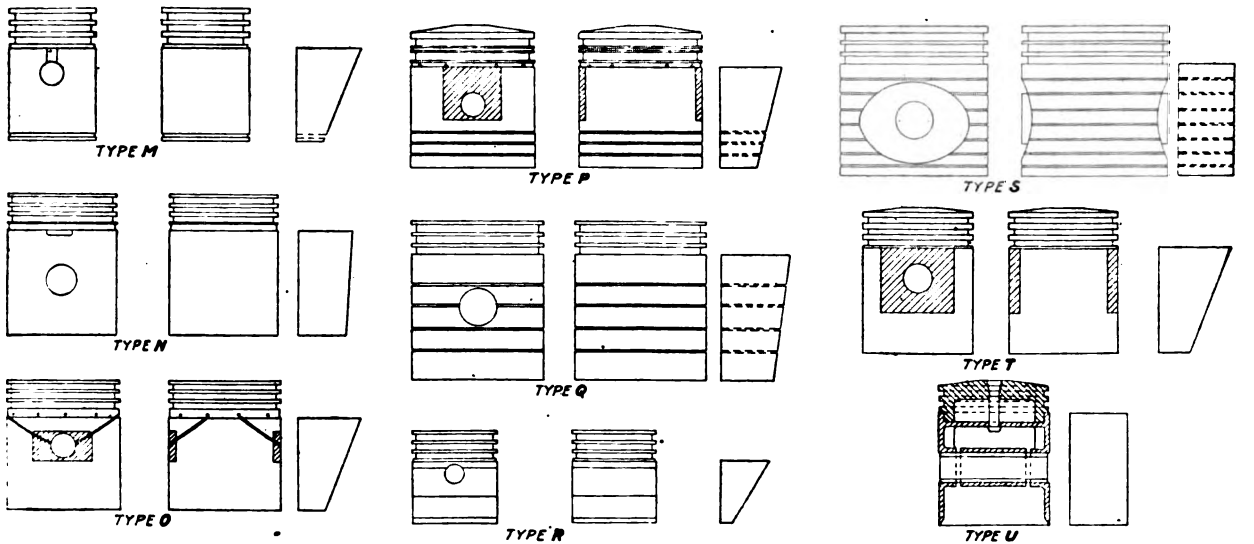

FIG. 9—OTHER FORMS OF PISTON WITH WHICH AMERICAN INTERNAL-COMBUSTION ENGINES ARE EQUIPPED

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(3) Friction of the piston against the cylinder wall and the wristpin bearing is omitted; these corrections are not only small but more-or-less self-compensating as the piston changes cycles

(4) The unit pressures indicated in the small sketches alongside of each type shown in Figs. 8 and 9 are obtained by the simple principle of the lever, assuming no bending, as mentioned in (2)

It seems logical that as a bearing crosshead Types *E*, and *K*, Fig. 8, and Types *N*, *P*, *Q* and *S*, Fig. 9, would prove much better than the others. The remaining designs appear to predicate excessive wear above the pin, with a large margin of useless skirt. Inasmuch as the piston serves as the medium of converting the greatest amount of useful work from the combustion-chamber to the crankshaft, its tightness once and for all is imperative. Long service cannot be expected if the piston is eccentrically loaded as a bearing. Many engines are in use today with plain cast-iron pistons that have done years of yeoman service, but they were designed so that they wore very slowly in service and thereby maintained their efficiency. I believe that a reversion to plain light pistons which are accurately made and proportioned would in general be beneficial.

As regards the matter of reduction in weight of reciprocating parts, might it not be well to assure ample durability of the piston and cylinder wall, using such material and weight as may be necessary, and making such reduction as may be possible in the connecting-rods? Materials suitable for such forgings that are materially lighter than steel seem to show promise at this time.

Referring to the engine characteristics in connection with constant-speed driving, the interesting results indicate a geared fourth-speed. No doubt the excellent mileage claimed by many foreign makers is made possible by this fourth gear.

E. FAVARY:—It may be possible to eliminate the engine knock by mechanical means, and perhaps to harness it or the indirect cause of it to increase the power derived from the products of combustion. According to indicator diagrams there is a rise in pressure in the cylinder that is so high and so rapid that it causes a knock. By reducing the compression pressure somewhat, the knock disappears. The sudden rise in pressure takes place at the beginning of the expansion stroke, when the piston velocity is comparatively low. It seems to me that by

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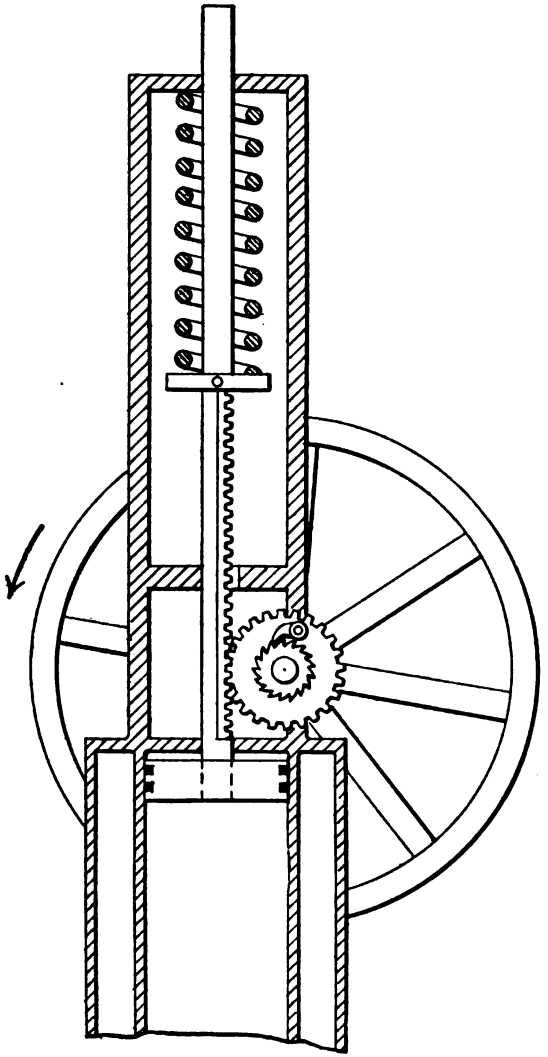

FIG. 10—A FOREIGN TYPE OF ENGINE IN WHICH THE HEIGHT TO WHICH THE PISTON IS THROWN BY THE IGNITION OF THE EXPLOSIVE MIXTURE IS REGULATED BY A SPRING WHICH ON THE RETURN STROKE DRIVES THE CRANKSHAFT THROUGH A RACK AND PINION

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using a cylinder-head or a combustion-chamber that yields under a pressure beyond that normally occurring in the cylinder at full load and just below the pressure at which knocking occurs, the knock could be eliminated and the mean effective pressure increased.

Fig. 10 is an illustration of an engine I saw in operation in Paris during 1897. Upon ignition of the explosive mixture the piston is thrown up as fast and as far as the spring will permit; on the return stroke the spring alone drives the crankshaft through the toothed rack and the gear wheel of the crankshaft. This engine, as I recall, had extremely high thermal efficiency.

Fig. 11 shows constructions that might prove useful for eliminating the knock and increasing the mean effective pressure. The drawings are diagrammatic, the valves and spark-plugs not being shown. This construction embodies a combustion-chamber of variable capacity so that under a partially closed throttle there is the same compression as under wide-open throttle. With a partly closed throttle, when the maximum pressure arising from the combustion of the charge is lower, the auxiliary piston descends until the maximum pressure in the cylinder is substantially the same as at wide-open throttle. In this manner the compression pressure is regulated by the maximum pressure. Several methods suggest themselves for reducing this system to practice.

The drawing at the left of Fig. 11 shows a small vent-hole in the top of the cylinder which will have the effect, in a measure, of preventing the upper piston from rising or descending rapidly. Instead of having the vent-hole where it is shown, the stem of the upper piston could be made to slide in a small sleeve having a vent-hole; this might be better adapted to regulating the speed at which the upper piston rises or descends. Making the upper piston heavy also would be found advantageous, on account of increased inertia effect. The spring can be located at the outside of the cylinder, instead of where it is shown, and it can be made to operate on the stem of such piston. Instead of using a spring, air might be compressed and caused to act like the spring. With this particular construction, suppose the piston were in a certain position at half-throttle, and that suddenly the throttle were opened wide, producing the condition under which knocking occurs. After two or three revolutions of the crankshaft the upper piston would rise by virtue of the increased pressure in the cylinder. This would not

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necessarily be due to the high pressure of the knock, but to the increased normal maximum pressure, until the knock disappears.

In the right-hand portion of Fig. 11 the upper end of the cylinder is entirely open or closed and the piston is made very light to reduce its inertia, so that at each firing of the charge it will rise at first. The upper piston can be made to begin to rise at say a pressure of 150 lb. per sq. in.; let us assume that the compression is just below that where self-ignition would occur. After the

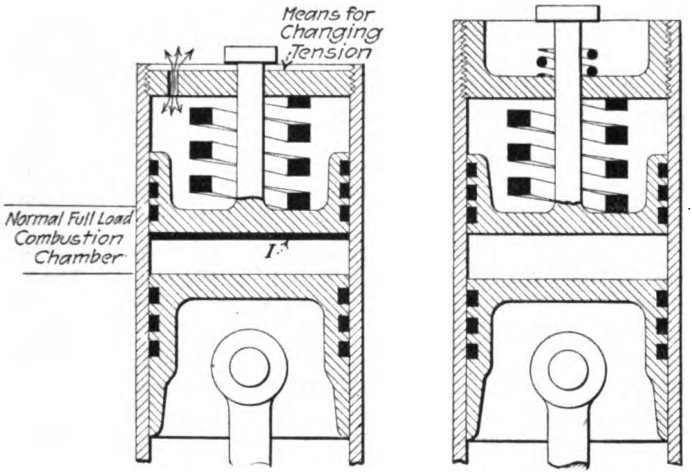

FIG. 11—SUGGESTED FORMS OF CONSTRUCTION FOR ELIMINATING KNOCKING IN AN ENGINE

ignition of the charge the piston would begin its upward course and the knock might even assist to force it up. Then, as the power piston descends during the expansion of the gas, it will follow the latter piston for some distance and thus keep up the pressure at the beginning of the expansion stroke. After the upper piston stops the expansion curve drops rapidly. The high pressure that is just below the pressure at which the knock occurs will increase the flame propagation from what it would be if the pressure were lower, and the expansion curve will therefore more nearly follow the adiabatic law.

Means can be provided for changing the tension of the spring in any convenient manner to vary the compression pressure. It possibly could be changed from the dash.

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This system will show a higher volumetric efficiency and the combustion-chamber will be smaller during the exhaust stroke; hence a smaller quantity of burned charge will remain in the cylinder. It may be possible even to expel substantially the entire burned charge by having the upper piston descend farther than is shown at the right of Fig. 11. On the suction stroke we should obtain a higher vacuum at the beginning of the stroke. This would fill the cylinder more thoroughly and the piston-heads could be insulated also, to decrease the thermal losses still further.

Instead of having the pressure in the cylinder raise the piston and having it stopped by a spring, mechanical means interconnected with the shaft might be employed which could be regulated so as to increase the volume of the combustion-chamber at the beginning of the expansion stroke or during any portion of any of the strokes. By having a high compression prior to ignition at all positions of the throttle, a very great saving in fuel might be obtained.

T. C. MENGES:—I wish to state the experience I have had in running stationary engines on kerosene. These engines are equipped with a throttling governor and a high-tension magneto and spark-plug. The difficulty with a kerosene engine is to get it to run well on a light load, or on no load. Fig. 12 illustrates the results of my experience.

First, the carbureter should be placed above the inlet-valve. We have placed the carbureter below and on the side, but the best location is up above as shown. The reason is that if any liquid kerosene drops down, it is drawn into the engine and does not form a slug when the throttle opens up for a heavy load. Another reason is that kerosene vapor will not rise easily; it seems to be a heavier vapor than gasoline, and will stick to the walls of the manifold. If we put the carbureter above the inlet-valve, we do not require as hot a manifold or as hot an intake of air. This gives better volumetric efficiency and the engine will run more satisfactorily. The carbureter on an automobile engine is usually placed below the manifold; consequently we have the same trouble in handling the lower grades of fuel that we had with the carbureter when it was located below the inlet-valve.

Second, the inlet manifold should be short. A manifold like that in Fig. 12 gives good results. In a long manifold unless the manifold is kept very hot, the kero-

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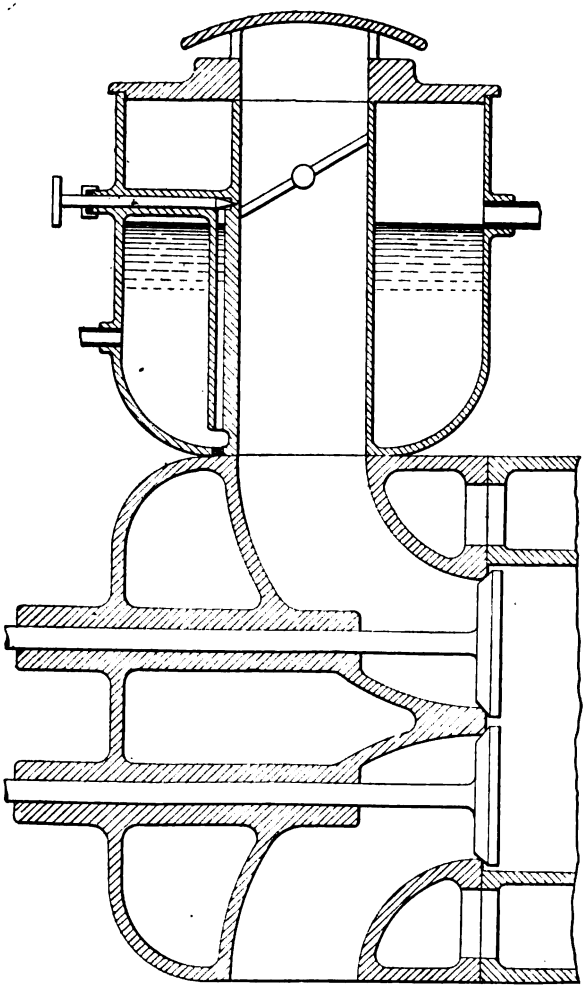

FIG. 12—SECTIONAL VIEW OF A PORTION OF A STATIONARY ENGINE DESIGNED TO BURN KEROSENE

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sene vapor will condense and form a poor mixture. Curves and turns in a manifold should be avoided. No extra heating of the mixture is necessary when the manifold is short. It seems that if we can get the fuel vapor into the cylinder without condensation, the engine will run well. We are able to run engines on kerosene without a hot-air manifold, and we do not need to use water to keep down the knocks. This probably is due to the fact that the vapor enters the engine in a fairly cool condition.

Third, the most important point is the location of the fuel nozzle. All automobile-engine carbureters seem to have the nozzle in the center and separated a long distance from the butterfly throttle-valve. This is all wrong for utilizing kerosene, and I believe it is wrong for utilizing the lower grades of gasoline. In Fig. 12 it will be noticed that the nozzle is in the side of the air-pipe. What is of greater importance is that it is located within 1/16 in. of the edge of the butterfly throttle-valve. We have tried all different locations and none of them works so well as the one shown in Fig. 12. The nozzle should be very close to the throttle, but this is impossible with the ordinary type of carbureter. If the fuel nozzle is located as shown, the engine will run well at any load or speed.

When the engine is running on no load, the butterfly throttle-valve is almost closed, and what little air passes into the carbureter must pass the fuel nozzle. This breaks up the liquid fuel and forms an explosive mixture. I believe that if the liquid kerosene could be broken up into a fine enough mist, an engine would start cold on kerosene. On the other hand, if the kerosene is not thoroughly broken up, an excess amount of heat will be required to vaporize it. One should be sure to locate the fuel nozzle on the side which forms the bottom sweep of the turn, so that the air does not need to hold the liquid in suspension, as would be necessary if it were on the upper side.

The substance of my experience in running stationary engines is that the three important features in utilizing kerosene fuel are (*a*) to locate the carbureter above the inlet-valve of the engine, (*b*) to use a short manifold with few bends, and (*c*) to place the fuel nozzle next to the edge of the butterfly throttle-valve.

G. HAMILTON GRAPES:—In reference to the fuel problem, the following improvements are needed to afford free growth to automotive plants and national production:

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(1) A halt to further dilution of standard gasoline by fractions having end-points above 400 deg. fahr.
(2) The addition to standard gasoline of 10 per cent of benzol or 20 per cent alcohol, or proportions of both
(3) The raising of all engine compressions by 10 per cent
(4) The employment of smaller and more efficient engines, and the lightening of chassis and bodies. All of this would represent a probable further 10-per cent increase in fuel efficiency and conservation
(5) The absolute gasification of the higher-boiling fractions, and the maintenance within minimum limits at maximum efficiency, by suitable automatic apparatus, of the temperature of the gaseous mixture prior to its entry into the engine cylinders. This would prevent the present waste of 10 per cent of standard gasoline now so evident in the excess of carbon monoxide and dioxide products in city service, in the dilution and deterioration of engine lubricants and in carbon deposits throughout the explosion chambers and in the gas exit passages of internal-combustion powerplants
(6) That the oil companies are best fitted by their organization to place economically upon the market a standard power fuel compounded with alcohol at a controlled price limit. Their cordial cooperation and coordination with the Society of Automotive Engineers in its efforts to solve this problem are most desirable, in the best interests of the public
(7) That the Government should install forthwith a laboratory, personnel and equipment to be entirely devoted to research work in compounded liquid fuels. This work should deal with constituent parts including alcohol, petroleum, benzol, shale oil and any other suitable medium. This activity should be supplemented by the production of power alcohol upon a limited commercial basis by State agricultural experiment stations
(8) The prohibition by the health authorities of the present fuel wastage by the emission of excess noxious gases by any motor vehicle, the result of incomplete combustion. This should be on the ground of danger to the public health
(9) A tax upon all cars weighing more than 2000 lb., or having a seating capacity of more than four adults. The proceeds should be allocated to fuel research work. This should reduce considerably the present loss in the transportation of non-profit-earning tare-weight which is now a fruitful source of gasoline wastage. If enforced, this tax would effect a fuel saving of at least 5 per cent

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Upon a conservative basis, it is reasonable to suppose that if these outlined suggestions were given a thorough trial, a saving of 40 per cent would be effected in the liquid-fuel supplies of the United States.

H. L. HORNING:—I had Mr. Nelson's advance experimental notes, and I examined the performance of the engine. From the size of the engine and the compression-ratio of 5 to 1, it seemed that the combustion efficiency should be 66 per cent or, in the more usual terms, the indicated thermal efficiency should be 66 per cent of the air-cycle efficiency. The air-cycle efficiency, which is a standard by which engine performance can be judged and is based on a fundamental characteristic of an ideal working fluid, is 47.5 per cent of the total energy in the fuel for a 5-to-1 compression-ratio. Therefore, 66 per cent of this would be 31.3, which is the indicated thermal efficiency. On examination of Mr. Nelson's results I found that he attained this efficiency at 2100 r.p.m., the speed at which the gas velocity through the intake-valve usually produces the highest thermal efficiency in overhead-valve cylinders. He started out to accomplish the elimination of the knock, the highest horsepower performance and the greatest possible ton-miles per gallon of fuel, in an engine. Mr. Nelson is to be congratulated on having practically accomplished these three results on his given product.

The lesson we can draw from his results is that by using a much smaller engine and thus limiting the horsepower still greater results in useful work can be accomplished. This is not a criticism of his paper; it is making the most of the information and conclusions undoubtedly indicated by the paper. In examining the curve of indicated thermal efficiency at speeds of 1000 to 1400 r.p.m., it will be noted that it rises very rapidly. This indicates that the turbulence at these speeds is very low, and it is not until the engine attains 2100 r.p.m. that we reach the highest efficiency. At the speeds just below 2100 r.p.m. however the curve of the indicated thermal efficiency rises with comparative rapidity and exceeds a 3-per cent range in 600 r.p.m. This indicates that the combustion efficiency has been neglected for volumetric efficiency. A lower-lift valve would have given a higher gas velocity and a greater efficiency at lower speeds, without sacrificing the volumetric efficiency in a marked degree and therefore sacrificing the horsepower. Mr. Nelson was able to get down to 0.51 lb. per

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b.hp-hr., which is a very creditable performance, but it is possible for him to attain a fuel consumption of 0.48 lb. per b.hp-hr. by increasing the combustion efficiency as suggested.

MR. NELSON:—Mr. Horning has carefully studied my paper and offered some very constructive criticism. The best performance of the engine does not come at full load; it comes at about 90 to 95 per cent of the full load. Under those conditions the economy will equal that of Mr. Horning's expectations. I have tried 0.375-in. valve-lift. The loss of maximum power is slight. A close comparison of results along Mr. Horning's line of suggestion has not been made, but it should prove very interesting. The striking feature of Mr. Horning's work is his ability to determine with great accuracy the results that should be obtained. It is clear to me that his work on turbulence is bearing fruit.

MR. HORNING:—In reference to Mr. Fieldner's paper, as liquid fuels have increased in end-point or decreased in volatility, a number of difficulties have developed in the operation of engines that are familiar to all. Among them are

(1) Difficulty of starting at low atmospheric temperatures
(2) Poor acceleration immediately after starting, particularly in cold weather
(3) Low miles-per-gallon performance
(4) Rapid deposits of carbon on the combustion-chamber walls
(5) Rapid wear of rings, piston-ring grooves and cylinder walls, due to diluted lubricating oil on the cylinder wall
(6) Dilution of the crankcase oil with the heavier constituents of the fuel and products of combustion
(7) High consumption of lubricating oil, due to a thinning of the oil by the fuel

These are the common forms of complaint and difficulty that are experienced with modern fuels. There are other ways in which the performance of the engine is affected. These need not be discussed at this moment. An analysis of all these results indicates that they arise largely from the incomplete vaporization of the fuel in time to be of value in producing power.

Outside of the tendency of the great bulk of the fuel available in the world to cause knocking in the engines and thus limit the power available from these fuels, namely the paraffines and olefines, the problem of vapori-

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zation is the most important one from the standpoint of conservation that confronts the engineer. It is therefore interesting to consider how the efficiency of vaporization can be ascertained. The indicated thermal efficiency of any engine is the percentage of the total energy of the fuel left after deducting the losses due to volumetric considerations and the loss of effective gaseous fuel due to poor vaporization. Carburetion efficiency is the ratio of the fuel actually burned to that supplied, or the ratio of the energy found in the indicated mean effective pressure to the energy which should be found in the mean effective pressure if all the fuel were burned. A way by which carburetion efficiency can be ascertained is testing an engine with a very volatile fuel, one which approaches as nearly as possible the form of fixed gases at practical temperatures. The most convenient fuels to use for this purpose are the better grades known as "aviation gasolines"; the standard test fuel should contain enough of the napthenes and aromatics to remove the possibility of detonation, auto-ignition or preignition. The procedure is to make a test of engines at the various speeds and loads with these better gasolines, finding the indicated thermal efficiency attainable under these various conditions. By dividing the indicated thermal efficiency by the air-cycle efficiency, the relative efficiency, which can be considered as a combustion efficiency, is ascertained. In this combustion efficiency we have a standard by which we can judge the performance of any engine and any fuel. The use of this standard is indicated by the following fundamental statement.

There is a limited range of air-to-fuel ratio by weight which can be fired in an engine. This varies from 8 to 1 to 17.75 to 1. With a fuel having a British-thermal-unit content of approximately 19,400 per lb., a mixture of perfect proportions has a ratio of 15 to 1. The maximum heat that it is possible to liberate is controlled by the oxygen present in the mixture. With a mixture having less fuel than the amount demanded by perfect chemical proportions, the amount of heat liberated is measured by the amount of fuel present. It is obvious, therefore, that the amount of heat liberated in any mixture, from the leanest that can be fired up to the chemically perfect mixture, is proportional to the fuel content of the mixture. Because any fuel over the amount necessary to consume all the oxygen cannot burn, this excess is of no value in producing heat and merely acts as a diluent, the same

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as an excess of air acts as a diluent. Since 1 lb. of air at normal temperature and pressure has a volume of 13 cu. ft., and it takes 15 lb. of air to burn 1 lb. of fuel, 195 cu. ft. of air is required for 1 lb. of fuel. Therefore, in 1 cu. ft. of mixture there are 19,400/195 or 100 B.t.u. Considering the cylinder to have a volume of 1 cu. ft., and the piston an area of 1 sq. ft., on the assumption of no losses, we would have the following thermodynamic relationship:

$$PV = W = FS$$

where

F = average force in pounds
P = average pressure in pounds per square foot
S = space range in feet
V = volume range in cubic feet of mixture
W = work done in foot-pounds

Thus in 1 cu. ft. of mixture we have as indicated above 100 B.t.u. If we multiply this by the constant 778 ft-lb. per B.t.u., we have the total number of foot-pounds of energy in 1 cu. ft. of standard mixture. If we divide this by the number of cubic feet, we have the number of pounds per square foot and, since there are 144 sq. in. in 1 sq. ft., we can thus derive the number of pounds per square inch by dividing the number of pounds per square foot by 144, or

$$P = E \div (144 \times 1)$$

where

E = the energy content of 1 cu. ft. of the correct mixture
P = the average pressure in pounds per square inch

Hence

$$P = 77{,}800 \div (144 \times 1)$$
$$= 540 \text{ lb. per sq. in.}$$

Since the amount of mixture drawn into the cylinder is always less than the swept volume, due to the restriction of the intake-valve, the manifold and the carbureter, and the temperature, the pressure obtainable would be reduced to that corresponding to the volumetric efficiency. If we calculate the indicated thermal efficiency from the air-cycle efficiency by using the combustion efficiency attained when using a perfect fuel as indicated above, we will find, with the less volatile fuels, that the following relationship obtains:

$$ITec \times E \times V > IMEP$$

or

$$Ae \times Ge = ITec$$

where

Ae = the air-cycle efficiency

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E = the number of British thermal units per cubic foot multiplied by 778 and divided by 144
Ge = the carbureter efficiency
$IMEP$ = the indicated mean effective pressure actually attained in the engine
$ITec$ = the calculated indicated thermal efficiency
V = the volumetric efficiency ascertained by measuring the weight, at standard temperature and pressure, of the air actually used, and dividing this by the swept volume of the engine

Therefore

$$Ge = IMEP \div (ITec \times E \times V)$$

In the days when the fuel had an end-point of less than 300 deg. fahr., the carbureter efficiency was very high. In those days the accidental heat given to the fuel in the carbureter and by the manifold, and the heat of the air, or in the cylinder, was sufficient to evaporate practically all the fuel. As the fuel began to recede in volatility, 300 deg. fahr. being the approximate initial point of kerosene, the manifold became more important as a means of supplying the heat essential for vaporization, and it was found necessary to heat the air to insure vaporization. With the next decrease in the volatility of the fuel, it became necessary to heat the manifold; and a considerable amount of the fuel was evaporated inside of the cylinder. On still further decrease in the volatility of the fuel, the manifold temperature assumed still greater importance and the cylinder reached the limit of its ability to evaporate the liquid fuel entering it, in time for effective combustion. With kerosene as fuel, the highest temperatures of the manifold and the cylinder practical in operation are necessary for reasonable carburetion efficiency. The fundamental consideration in the designation "carburetion efficiency" is that the function of the carbureter as originally intended to vaporize the fuel as well as meter it has been spread from time to time toward the piston of the engine. Therefore, while the carbureter is not now performing the function of vaporization, other elements in the engine are pressed into service to accomplish this result. It is thought proper to call the efficiency of vaporization "carburetion efficiency." The letter G is used to denote the fundamental necessity of having the fuel in the form of a gas. We can assume that the cause of low thermal efficiency in modern engines burning the heavier fuels at compression-ratios below that of detonation, is due to low carburetion efficiency.

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Notwithstanding that the temperature of the ingoing mixture is only approximately an index of its condition, this index gives us a basis on which to chart the efficiency of vaporizing systems on modern engines. Since it is the index of the atomization of the fuel at the nozzle of the carbureter and the vaporization in the intake-manifold, it is a fair basis of judgment of different systems of vaporizing. Since the end-point of various fuels is associated with that proportion of fuel which resists vaporization, this can be taken as an indication of the fuel value from a vaporization standpoint. If we take an engine or a series of engines with different kinds of carbureters and vaporizing systems and list them with respect to the temperature of the ingoing charge, we have a basis for testing one of the fuels available. Testing this fuel, we will find that, as the intake temperature increases, the carburetion efficiency also increases within limits. If we take a number of fuels having increasing end-points, and plot the results of these different fuels with different

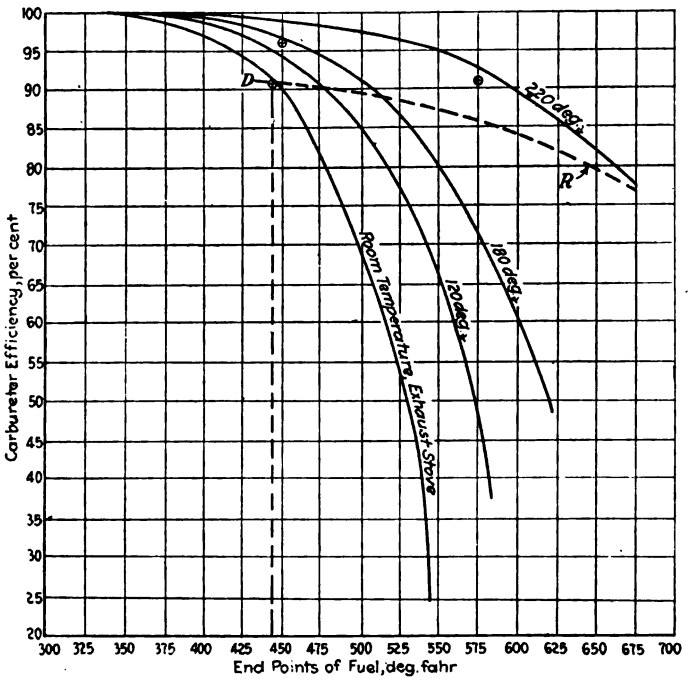

FIG. 13—CURVES SHOWING THE RELATION BETWEEN CARBURETER EFFICIENCY AND THE END-POINT OF THE FUEL

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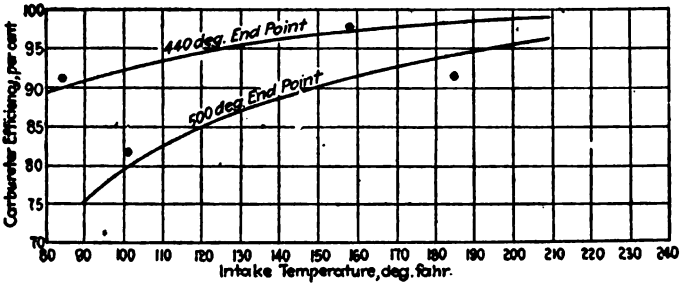

FIG. 14—CURVES SHOWING THE RELATION BETWEEN THE CARBURETER EFFICIENCY AND THE INTAKE TEMPERATURE

systems, we will have a complete graph of the effect of different systems of vaporizing with fuels of different end-points on carburetion efficiency (See Figs. 13 and 14).

In Fig. 13 the point *D* on the room-temperature exhaust-stove curve, denoting the system used on the Ford, is a very interesting point and of equal importance to the automotive and the petroleum industries. This point is the end-point of the standard gasoline according to the present Government specifications, and happens to be at such a place on the curve that a 10-per cent increase in the end-point will represent a 10-per cent decrease in the carburetion efficiency. The result is that there would be no economic gain, inasmuch as there would be no power delivered for the additional fuel bought or supplied. By running the line of 440-deg. end-points vertically through the other curves, we have the 440-deg. end-point curve of Fig. 14 which, interpreted, means that for any further increase in end-point there will have to be a corresponding increase in the intake temperature. If, in Fig. 13, we investigate the curve of 180 and 220-deg. intake temperatures, we will get a curve ending in *R*. This curve is what is known to economists as the "curve of diminishing returns." The line shown is for full load and at 1000 r.p.m. and, since the carburetion efficiency is highest at full load and higher speeds, this *D-R* line represents the maximum attainable. Ascertaining the *D-R* line for various loads and speeds would give all the vaporization data necessary and when determined from actual conditions would be of immense value. I submit that this is exactly what the automotive and the petroleum industries desire to know. Perhaps the public desires to know it more than anyone else.

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I submit that this is the curve which should be the object of our immediate research efforts. It is the common ground on which the industries involved and the public can measure their exact position. It is the only curve by which designers of automotive apparatus can direct their efforts, as well as the only curve by which the petroleum industry can tell whether additions of heavy fuel are of any value to the public when used in the apparatus available. A meeting of the Joint Committee of the Petroleum and Automotive Industries, the Bureau of Standards, the Bureau of Mines and the Society of Automotive Engineers unanimously approved a program of fuel research to be supported by these agencies of which Figs. 13 and 14 illustrate a skeleton representation of procedure and objective. It seems certain that the most urgent immediate research is the efficiency of vaporizing systems with respect to the increased specific gravity of fuels.

With respect to the problem of applying the theories

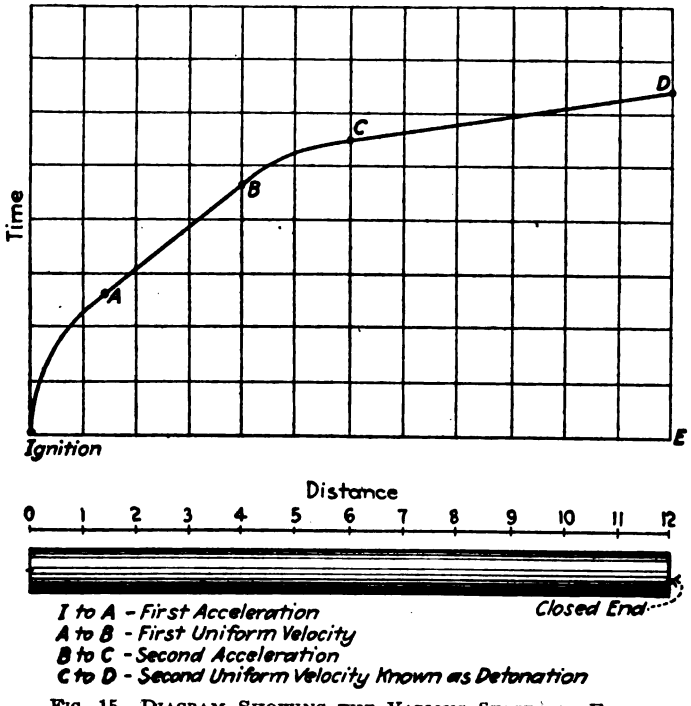

FIG. 15—DIAGRAM SHOWING THE VARIOUS STAGES IN FLAME PROPAGATION IN A TUBE HAVING A CLOSED END

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of flame propagation to the phenomena which occur in the cylinders, the following is a theory that our company has developed and used in research work. Referring to Fig. 15, *I-E* is a pipe in which a combustible mixture is ignited at the point *I*. As flame travels along the pipe toward the end *E*, the velocities change according to the order hereinafter described. An examination of a large number of flame photographs indicates that there are four possible phases in the velocities of the flame in a tube of uniform cross-section, not all of which are apparent, but which are approximated in nearly all mixtures. The four phases through which the velocities pass are as follows: As the flame travels from *I* to *A* it accelerates; this phase is known as "the phase of first acceleration." As the flame travels from *A* to *B*, it takes a uniform velocity. This phase is known as "the first phase of uniform velocity." As the flame travels from *B* to *C*, it passes through its second acceleration, and is so known. As the flame travels from *C* to *D*, it attains a uniform velocity and continues at this rate, which is known as "detonation." The use of a tube in the study of flame propagation is merely a device for drawing out the process of ignition, and for developing these four phases of flame velocity. The tube tends to establish the condition of quiescence and thus remove such artificial physical factors as stimulate the rate of reaction outside the condition of temperature and pressure. Since the flame travels into an entirely fresh mixture undiluted by products of combustion, the mixture is successively subjected to a rapidly increasing condition of temperature and pressure restrained by constant area of the flame crest, the chemical stability of fuel and dissociation.

However, it seems probable that with all hydrocarbon fuels, after a certain velocity of flame is reached, the catalytic action of the hydrogen ion has a decided influence on the rate of flame propagation, and it is entirely probable that an incandescent particle of glass may initiate some of the changes in velocity. Sound-waves traveling through the mixture tend to add compression effects and they can be seen traversing the regions of partial combustion, causing increased brilliancy of flame, and thus can be considered as augmenting combustion. Whatever phenomena may exhibit themselves in the idiosyncrasies of flame velocities can be considered as the resultants of all these factors.

For the practical man, we can set forth some seeming

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certainties based on thermo-chemistry. The region *B-C* represents a condition of combustion which, if it were possible to attain homogeneity throughout the mixture, would produce the highest thermal efficiency. The successive stages of *C-D* represent an increasing presence of too rapid a combustion of some of the contents, with the resultant incandescence of solid carbon particles. These represent an increasing loss due to direct radiation and, no doubt, the heat affects the regions of unburnt mixtures and accounts for a rapidly increasing reaction in these regions of flame. The point *C* also is favorable from a dissociation standpoint and may therefore symbolize the best compromise in practice between the controlling chemical and physical factors with respect to the highest thermal efficiency.

Phase *A-B* can be considered as the rapidity of combustion corresponding to lean mixtures and low loads and, from a thermodynamic standpoint, is characterized by a smooth sweet running of the engine.

Phase *B-C* can be considered to represent the combustion of the most economical mixtures for loads at and under that giving maximum economy, provided there is no marked or incipient auto-ignition. This is at nearly full-load performance and with lean mixture of low-compression engines down to normal running. This performance is not characterized by any roughness.

Phase *C-D* is characteristic of the engine having a compression just low enough to avoid detonation at the most economical mixture, but which is running with a richer mixture. This may also be representative of an engine running when the ratio is somewhat too high for available fuels; running at full throttle either accelerating or at full load. The action corresponding with this is a very rough performance and the effects can easily be felt as well as heard.

Phase *D-E* is one represented by the very rough performance of an engine in which the compression-ratio is too high for the fuel available, the engine running at full load on a perfect mixture, and is about as rough as can be imagined. The roughness is greatest at the speed of maximum torque, which is at relatively slow speed.

The first phase is one in which the flame is of a blue color. In the second phase the intensity of color increases and sometimes approaches green. This is the very best and most efficient type of combustion. The third phase is one in which a yellow color is emitted from the

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flame, and the fourth one in which the flame has a brilliant white appearance.

A tube has the limiting feature of a small uniform cross-section and it therefore is obvious that the only way in which a given volume of explosive mixture can be consumed in a relatively short time is by the use of a high velocity of the flame crest. Inasmuch as the efficiency of combustion is represented by the velocities not exceeding *C*, the problem of combustion in an internal-combustion engine resolves itself into a resort to other means of increasing volume consumption than by flame velocity. The theory used and developed by us is the theory of maximum areas. This involves the simple geometrical fact that a volume is generated by an area sweeping through a given distance. In other words, in a quiescent mixture the most effective way of consuming the greatest volume of it in the shortest space of time is to provide a shape of chamber in which the flame surface or crest can spread out, developing at each successive advance an increasing area of contact with the unburned mixture. Referring to the upper left portion of Fig. 28, in which we have a conical-shaped chamber and in which the lines drawn are the successive positions of the flame crest at uniform intervals of time in the form of chamber shown the area of the crest decreases very rapidly. In the lower left corner, with ignition starting at *I* and with lines representing the advance of the flame in equal divisions of time, we have a form which favors the development of a large area of the crest with each successive advance of the flame. It can be shown that the volume consumed in this form increases as the cube of the distance from the firing point and, since the distance traveled may vary in some mixtures roughly as the cube of the time, it will be seen that great volumes can be consumed in very short intervals of time. This high rate of volume consumption is based on the assumption that the flame is traveling into unburned mixtures and does not take dissociation or dilution into consideration. If we make a figure of two cones, starting the ignition at the peak as shown, the flame will then travel out as indicated and we will therefore have consumed twice the volume of mixture in the same length of time. If we generate a sphere with a great number of cones and ignite the mixture at *I* at the center, we will consume the greatest possible volume in the given time. It has been found by tests of explosive mixtures in vessels having approxi-

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mately the form of a sphere that the rapidity of rise in pressure is maximum when the mixture is fired at the center, and at a minimum when the mixture is fired at one side. All these considerations have been based on a quiescent mixture.

The next expedient which suggests itself is that of furnishing many points of ignition. This again affords a means whereby great volumes of explosive mixtures can be fired without reaching high unit velocities of the flame at any point of the mixture. Thus, the diagram in the lower right-hand corner of Fig. 16 can be conceived to be a sphere of very small diameter and with many ignition points; we have many spheres merging into each other.

TURBULENCE

The other means available for increasing the volume of explosive mixtures consumed in a given time is stirring up the mixture and producing in it what is known as turbulence. If we produce a rapid enough circulation of the gases, it is possible by igniting them at the point of greatest rapidity of movement to approach approximately the effect of a multitude of ignition points. With this

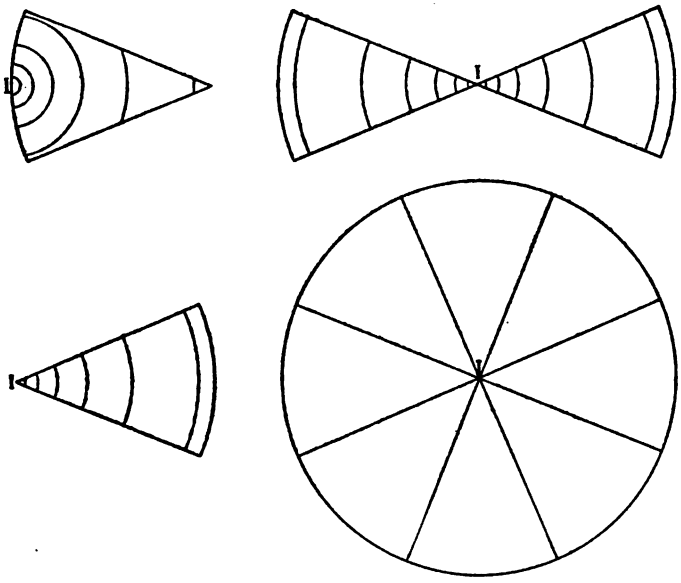

FIG. 16—DIAGRAM SHOWING THE INCREASE IN THE AREA OF THE FLAME CREST IN DIFFERENT FORMS OF COMBUSTION-CHAMBER

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large number of ignition points distributed throughout the mixture, it is possible to initiate numerous spheres of flame and therefore an infinite number of small velocities and rapidly increasing flame areas and hence the maximum volumes in a unit of time without approaching the flame velocities of detonation. There are other considerations such as the area-volume ratio and the fact that spark-plugs have to be situated at the outside of a sphere. These need not be discussed here, other than to call attention to the fact that, because of the cool layer of gas on the walls of a combustion-chamber, turbulence insures a larger volume of gas consumed in a given time by driving the surface gas off into the flame and thus replacing it with the burned products of combustion. In a sphere the relative volume of these layers is minimized.

The process of turbulence is merely a physical assistance to the process of chemical reaction by assisting the kinetic tendencies of one species of molecules to make contact with those other species with which they must unite under the conditions in the cylinder. The process of chemical reaction, of which combustion is one type, is a surface phenomenon. The most modern conception of the constitution of the atom is that the electrons in the outside layer are the ones which give the atom of molecule its chemical properties. Therefore, when we develop the maximum of flame-swept volume by adopting those shapes of combustion-chamber which will allow the most rapid development of flame-crest area for both mixtures of a relatively quiet nature and those aided by turbulence, we follow the most fundamental law of chemistry. In very slow combustions the reaction of hydrocarbons is in very many steps; as the reaction increases in rapidity the chemical stages through which a unit volume of mixtures passes become more direct, and it seems from all known considerations that the most thorough and best-controlled combustions are those in which the combustion-chamber can be considered to be filled with a mixture comprising a large number of small volumes in which the initial and end-stages of combustion are occurring at one time, intermingled with the products of combustion and their dissociations. There should, therefore, be a general homogeneity throughout the mixture rather than a progressive change of reaction from one part of the mixture to the other. The ideal condition would be that in which the various reactions going on in any small unit section at any one time are typical of those in a section of sim-

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ilar size in any part of the mixture. This is the very antithesis of the conditions in a tube.

There are three kinds of knock which are vaguely understood

(1) The knock which comes by igniting the charge too soon, and this can be produced either by the ignition system of the engine or by some hot-spot in the combustion-chamber
(2) The knock caused by pure detonation or, in other words, what occurs when an engine is running very slowly and the flame traveling in a mixture that is approximately quiescent
(3) The knock produced by auto-ignition, due to the shape of the combustion-chamber with a slow-burning mixture in which a virtual pocket of unburned gases fails to burn by the time maximum temperatures are reached; or, due to fuel left over at the high-temperature point, because of slow-burning mixtures; or, due to a two-stage combustion or a combination of all three of the above causes.

I know of no factors governing chemical reaction which turbulence does not assist in producing the most effective types of combustion and in controlling the knocks listed above.

L. H. POMEROY:—Mr. Nelson's paper constitutes a very important link in the chain of problems correlating the behavior of an engine on the test-block with its performance under working conditions, and the nature of the extended experimental work he has done is not less important than the complete description of conditions and general data that are usually conspicuous by their absence in such discussions. The results obtained from the point of view of mean effective pressure and thermal efficiency are those appertaining to a first-class engine but it is interesting to find that the results obtained in an overhead-valve engine with a compression-ratio of 5 to 1 in the above respects are almost identical with those obtained with a new four-cylinder engine with a 4¼-in. bore and a 4¼-in. stroke with a 4½ to 1 compression-ratio and side-by-side valves, indicating once more that the difference in the possible performance of engines of widely differing design is affected very little by the disposition of the valve gear and that the limiting factor in the compression-ratio is that at which detonation is absent, thus allowing the higher compression-ratio that can be used on small-bore engines to compensate for their inherent higher heat-losses.

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I was particularly interested in Mr. Nelson's vaporizer as the publication of this coincided with the middle of a slough of despond occasioned by the difficulty of getting satisfactory results from present-day fuel. Many attempts were made to overcome the difficulties arising from loading and deposition, including a strenuous attempt at the use of a fuelizer that proved an exceedingly hit-or-miss apparatus, to say nothing of increasing fuel-consumption about 12 per cent. These disappointing results were, of course, directly chargeable to my lack of skill in designing and applying the fuelizer, so that the immediate success obtained by using Mr. Nelson's vaporizer was all the more welcome. From the carburetion point of view my engine presented much more serious problems than Mr. Nelson's and I am happy to corroborate his statements as to the capacity of the vaporizer for overcoming carburetion difficulties at low speeds without sacrifice of power at high engine-speeds.

The problem of fuel reduction in automobiles, apart from any alteration in the working cycles, is primarily dependent upon the internal friction of the engine and the weight of the chassis. Taking Mr. Nelson's results, from Fig. 25, the mean effective pressure developed at 23 m.p.h. or a speed of 1000 r.p.m. with 4.5 to 1 gear-ratio is approximately 16 lb. per sq. in., this being about 17 per cent of full load as shown on Fig. 24. At the same speed the friction mean effective pressure is about 10 lb. per sq. in., the mechanical efficiency of the engine at this speed therefore being about 61 per cent. We see then that the indicated mean effective pressure under the above conditions is 26 lb. per sq. in., of which 10 lb. per sq. in. is required to overcome internal resistance in the engine, while the remaining 16 lb. per sq. in. is required to overcome the internal friction of the car apart from the engine. Of this latter overwhelmingly the greater portion is absorbed in the friction drive between the wheel and the road, in the tires, the gear losses probably not exceeding 5 per cent in all.

The line of development to reduce fuel-consumption seems to be clearly indicated and involves (*a*) the reduction of the car weight and the tractive effort that absorbs the greater part of the power developed and (*b*) the reduction of the internal friction of the engine that also absorbs a very considerable amount of energy. I would emphasize the point that it is not mechanical efficiency as such that is the criterion of internal resistance in engines but that attention must be focused upon

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the absolute losses. This will readily be seen when one considers that it is possible to have two engines having the same mechanical efficiency due in the one case to a high indicated mean effective pressure with correspondingly high internal losses and in the other case of the low mean effective pressure and low internal losses. The latter engine would under normal road conditions of partial throttle make a considerably superior showing than in the alternative case. In point of actual fact the internal losses in the engine described by Mr. Nelson are very low indeed and can safely be taken as minimum figures in designing a new engine.

I am somewhat surprised at the slope of the indicated consumption curve in Fig. 25 and would ask Mr. Nelson whether he can suggest any reason for the fact that this curve is not much more nearly parallel to the axis of abscissas.

MR. NELSON:—I do not agree with Mr. Pomeroy that the L-head type of engine compares with the valve-in-the-head type. The results that he mentions may be nearly identical, but the way of obtaining the results is widely different and the deciding factors do not have any basic relation to the type of engine or the nominal compression-ratio. I am familiar with the details of Mr. Pomeroy's engine. The results he obtained at full load, as far as the indicated mean effective pressure and thermal efficiency are concerned, follow from larger valves and a larger carbureter in proportion to the size of the engine in question, and a rather early closing of the intake-valve that gives about the same final compression pressure as the 5-to-1 compression with the delayed timing. At higher speeds the mean effective pressure is obtained in his case by larger valves and carbureter, that is, by a higher volumetric efficiency. Considering these factors, it is easily seen that a direct comparison of 4.5 and 5 to 1 compressions is indeed very misleading. We made some experiments with a camshaft such as Mr. Pomeroy's and with 4.25 to 1 compression obtained even higher mean effective pressures than given in these tests. However, at the higher speeds our valves were not large enough to maintain a good volumetric efficiency and the results were not as good as Mr. Pomeroy's with 4.5 to 1 compression. This type of camshaft was not tried with 5 to 1 compression since it was obvious that the mean effective pressure would be so high at low speed as to be untenable with our present-day fuel.

To obtain better economy at partial loads the 5 to 1

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nominal compression was used with a delayed closing of the inlet-valve. This results in a very material decrease in the actual compression-ratio. The latter is computed from the volume in the cylinder at the time of the inlet-valve closing and the final volume after compression. The most important point brought out by the tests is that the gain in economy by the higher nominal compression-ratio is far greater for partial loads than for full loads. The gratifying thing about this is that the partial-load economy is far the most vital and the one about which we should concern ourselves more fully in the future.

I am very glad indeed that Mr. Pomeroy, with others, has proved to his satisfaction that the vaporizer performs as set forth in my paper. Mr. Pomeroy mentioned that his carburetion problem was greater than that of the tests submitted. This is an important point. I think we will agree that with the usual small carbureter and small intake-passages the distribution problem is not nearly as difficult as with large carbureters and large intake-passages. I was very much gratified to learn that with proper vaporization I could use as large a carbureter as I chose. The 2-in. carbureter worked equally well on engines as small as 183 cu. in. On the other hand, with some types of heating arrangement that I have tried I could not run even at the medium low speeds, to say nothing of a speed as low as 200 r.p.m. with a wide-open throttle. It is experiments like these and results such as Mr. Pomeroy is getting that drive home the importance of proper vaporization.

It is obvious that one would expect the indicated thermal efficiency curve of Fig. 25 to slope. At 10 m.p.h. only a very small charge enters the cylinder and the actual compression of this charge being small results in a low indicated thermal efficiency, as one would expect from the laws governing the Otto cycle. As the speed increases the load factor of the engine increases, that is, the actual compression of the gas increases, resulting in a higher thermal efficiency. Mr. Pomeroy apparently was not bearing in mind the partial-load conditions when he asked for this explanation.

If engineers will cooperate more closely in the future we will advance faster. We should tell of important details affecting results, as mentioned by Mr. Pomeroy.

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AIR-TEMPERATURE REGULATION EFFECTS ON FUEL-ECONOMY

By Reuben E Fielder[1]

Two serious problems confront the automotive industry in connection with the present fuel shortage, the securing of a much higher degree of fuel economy with existing equipment and the matter of future designs. These problems are of nearly equal importance.

Because its fuel bill constitutes the second greatest item of expense for the Fifth Avenue Coach Co., operating in New York City, it is constantly experimenting with devices of various kinds to improve fuel economy. Of the different devices that it has tested, the thermostatic temperature-control for the carbureter appears to afford greatest possibilities of saving, and the author presents the results of tests of this device in actual service on motor vehicles.

The thermostat is shown and described and comparative tests made with and without this thermostatic-control device, using the same engine, carbureter and similar equipment, under the same atmospheric conditions, are discussed and analyzed with the aid of tabulated data and charts. The matters of temperature variation and the volatility of fuel are treated in a similar manner, consideration then being given to what the desired manifold temperature is. Volumetric efficiency is discussed in some detail.

The paper was presented with the primary idea of bringing out constructive criticism. The company believes that the principle of thermostatic control is correct, but that its detailed application is still a matter for further experiment. That there are certain periods during the year when the average internal-combustion engine functions with the minimum amount of trouble is scarcely open to argument. This is because at that time the atmospheric temperature is right. The company's idea is to select this period and standardize it for use throughout the remainder of the year.

Two serious problems confront the automotive industry in connection with the present fuel shortage. First, there is the problem of securing a much higher degree of economy with existing equipment; then, apart from this, there is the matter of future design. These problems are of nearly equal importance, since existing equipment will undoubtedly be in operation for a number of years to

[1]M. S. A. E.—Mechanical engineer, Fifth Avenue Coach Co., New York City.

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come; yet nearly all of the authorities on the fuel question are confining themselves to the future. As we see the situation, it is highly desirable that some attention be paid to the problem immediately facing us.

The steadily increasing cost of gasoline is a particularly serious matter for the Fifth Avenue Coach Co. The price paid today is practically four times what it was when we began to operate, although our rate of fare remains the same. We use several million gallons of gasoline each year; our fuel bill constitutes our second greatest item of expense. For this and many other reasons, we are constantly experimenting with devices of various kinds to improve fuel economy. Of the different devices that we have tested, our thermostatic temperature-control for the carbureter appears to afford greater possibilities of saving than anything else that has been brought to our attention.

I will present briefly the results of our tests of this device. Although they show an appreciable saving, the device is still in its early stages of development and presents further possibilities for research. This can be accelerated, we believe, by placing what data we have at this time before the automotive industry.

Description of Thermostat

Of the various factors governing the economical use of present-day fuel, we believe that the control of the charge temperature will play a most important part. Fig. 1 shows the latest development of the thermostat for the control of the charge temperature in the inlet-manifold. In this apparatus the air enters a stove. This is cast around the exhaust-manifold in such a manner that the air passes along the top and then downward and back along the bottom of the exhaust-manifold, which gives the maximum contact of the air with the hot surface. The air then passes down a pipe in which is located a double sleeve-valve controlling a cold-air inlet. The air continues on through the carbureter into the inlet-manifold, where a spiral of thermostatic metal is located which connects to a spindle controlling the cold-air valve. The air, after mixing with the gasoline from the jet, strikes the thermostat which, according to the temperature, opens or closes the cold-air valve and thereby regulates the charge temperature which has been predetermined to suit the grade of gasoline being used. The temperature in the inlet-manifold can be varied by ad-

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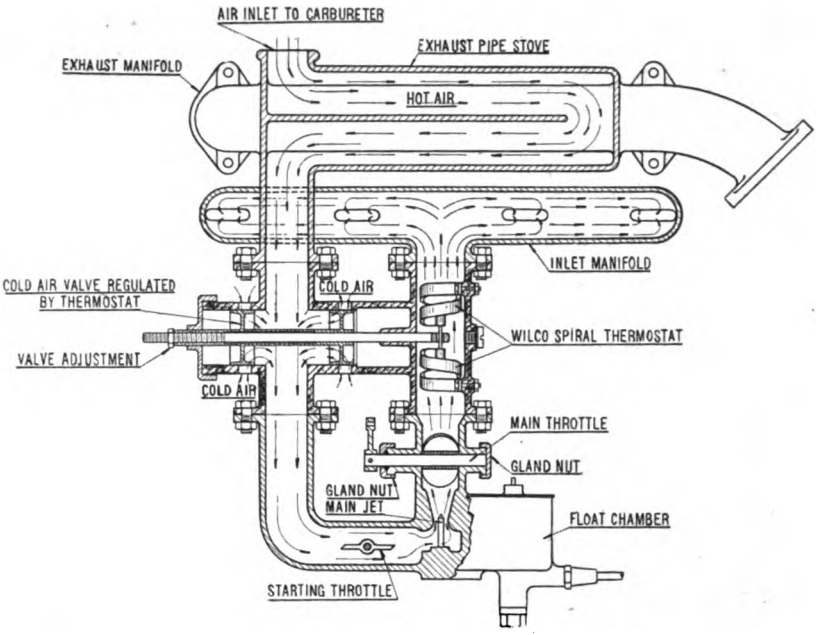

Fig. 1—Sectional Elevation of Thermostat Control for Air Entering the Carbureter

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justing the relation of the cold-air valve with its inlet ports. Air leaks are a source of trouble and it is necessary that all joint gaskets be tight. We have found also that it is advantageous to use packing glands around the throttle spindle.

Comparative Tests

Comparative tests have been made with and without this thermostatic-control device, using the same engine, carbureter and similar equipment, under the same atmospheric temperature conditions. The results are shown in Fig. 2, where the average saving in fuel-consumption is 7.85 per cent and a 5-per cent increase in horsepower was obtained when using the thermostatic control. We have obtained a greater saving than this in other tests, but the figures given can be considered most conservative. Table 1 shows comparisons taken from Fig. 2.

TABLE 1—ECONOMY TEST

Speed, r.p.m.	Standard Equipment	Thermostatic Control	Difference	Difference, per cent
	Power Developed, Hp.			
400	10.5	11.2	+0.7	+6.6
600	17.7	18.0	+0.3	+1.7
800	21.5	22.5	+1.0	+4.6
1,000	25.3	26.3	+1.0	+3.9
1,200	27.6	28.2	+0.6	+2.2
			Average	+3.6
	Fuel Consumed, Lb. Per Hp-Hr.			
400	0.702	0.664	—0.038	+ 5.4
600	0.628	0.598	—0.030	+ 4.8
800	0.626	0.588	—0.038	+ 6.1
1,000	0.655	0.590	—0.065	+ 9.9
1,200	0.694	0.622	—0.072	+10.3
			Average	+ 7.3
	Manifold Temperature, Deg. Fahr.			
400	139	101	—38	—27.2
600	150	101	—49	—32.6
800	159	101	—58	—36.5
1,000	144	101	—43	—29.8
1,200	131	101	—30	—23.0
			Average	—29.8

The temperature in the manifold when using the thermostatic control was constant, whereas without this device it varied from 130 deg. fahr., as a minimum, to 160 deg. fahr., which showed a loss of power and increased consumption of fuel at all speeds, indicating a loss in volumetric efficiency due to excessive heat. This test was made at a time when the atmospheric temperature was 68 deg. fahr. What happens when the atmospheric temperature is around 90 deg. fahr. as in the

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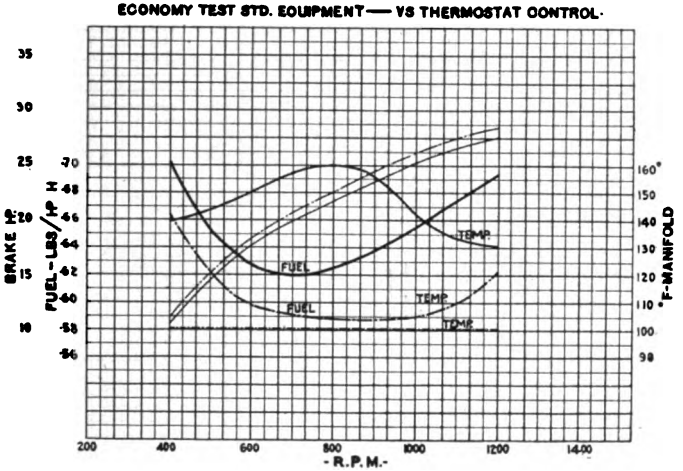

FIG. 2—RESULTS OF ECONOMY TEST SHOWING SAVING IN FUEL-CONSUMPTION AND INCREASE IN HORSEPOWER OBTAINED AS A RESULT OF USING THE THERMOSTATIC CONTROL

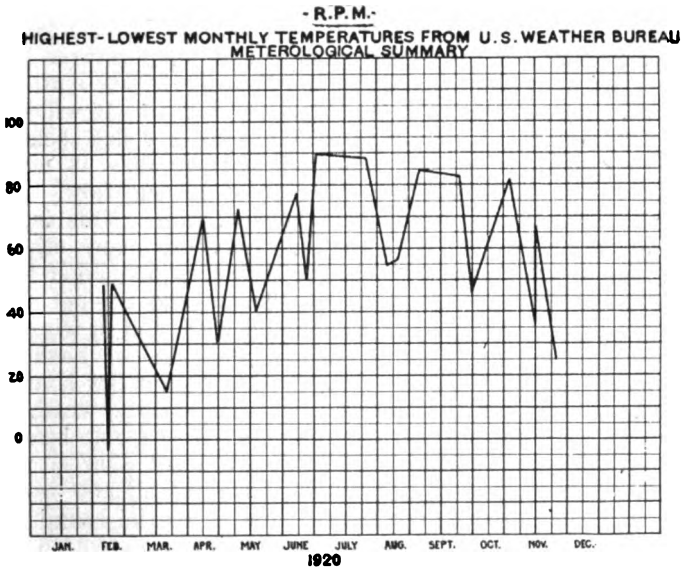

FIG. 3—MAXIMUM AND MINIMUM MONTHLY TEMPERATURES AT NEW YORK CITY FOR THE YEAR 1920

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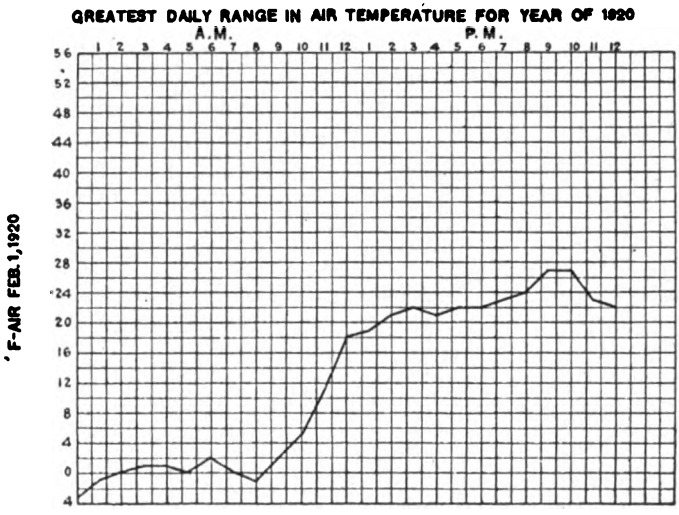

FIG. 4—A TYPICAL CHART SHOWING THE DAILY RANGE IN TEMPERATURE

summer, or 0 deg. fahr. as in winter, can well be imagined.

TEMPERATURE VARIATION

Fig. 3 shows the highest and lowest temperatures by months for 1920, taken from the New York City station reports of the United States Weather Bureau. It will be noted that the temperature in February is 4 deg. below zero fahr.; yet in the same month it reaches 48 deg. above zero fahr., which is a range of 52 deg. fahr. In July the temperature reaches 90 deg. fahr. This is a considerable degree of heat, but there are many other things which make it worse; for instance, in summer we have the radiation from the pavements and the hot air coming from the radiator to contend with, and in winter bleak winds are encountered. In addition, we have a considerable temperature range within even a few hours, as is shown in Fig. 4, which is taken from the weather report for Feb. 1, 1920. At midnight, it is 4 deg. below zero fahr. and continues below zero until 8.00 a. m. Then it rises 20 deg. in the next 4 hr. and at 9.00 p. m. it is 27 deg. above zero fahr. This is a total range of 31 deg. for the day, which is by no means an exception.

The volatility of gasoline has changed considerably since 1915 as is shown in Fig. 5. This is a fuel-

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distillation curve supplied by the United States Bureau of Mines and the comparisons are shown in Table 2.

TABLE 2—COMPARATIVE FUEL DISTILLATION CURVES

Year	First Drop, deg. fahr.	Amount Distilled at 212 Deg. Fahr., per cent	Dry Point, deg. fahr.
1915	95	40	360
1920	133	22	446

The thermostat is set to control the manifold tempera-

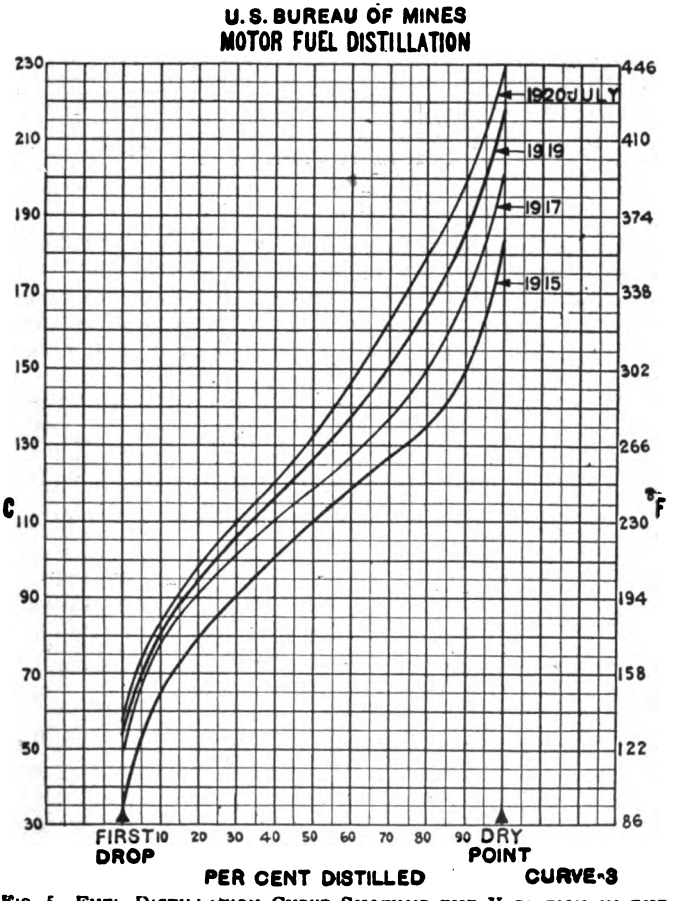

FIG. 5—FUEL DISTILLATION CURVE SHOWING THE VARIATION IN THE VOLATILITY OF GASOLINE BETWEEN 1915 AND 1920

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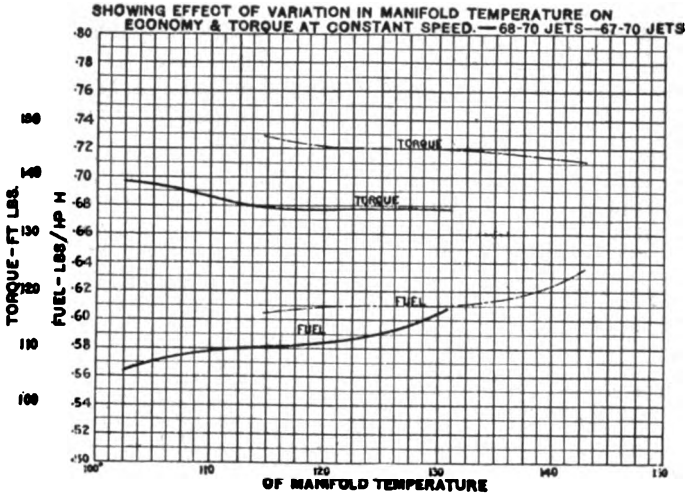

FIG. 6—THE EFFECT OF VARIATION IN MANIFOLD TEMPERATURE ON FUEL ECONOMY AND TORQUE DEVELOPED

ture at about 102 deg. fahr. This temperature was determined upon after tests in which the engine speed was held constant while varying the temperature in the manifold, the power developed and the fuel-consumption being recorded. The speeds selected were 700 and 1200 r.p.m., thus representing the high and low range of speed.

Fig. 6 shows two tests at 1000 r.p.m. with 68-70 and 67-70 jets. The No. 70 jets were used only for starting and idling speeds. The comparison with a No. 68 jet, shown in Table 3, is interesting and indicates a loss in volumetric efficiency due to the expansion of the air at high temperature.

TABLE 3—EFFECT OF VARIATION OF MANIFOLD TEMPERATURE ON ECONOMY AND TORQUE, WITH DIFFERENT JETS

Temperature, deg. fahr.	Jets 68-70	Jets 67-70	Difference	Difference, per cent
	Fuel Consumed, Lb. Per Hp-Hr.			
115	0.581	0.605	+0.024	—4.1
120	0.585	0.609	+0.024	—4.1
125	0.591	0.610	+0.019	—3.2
130	0.605	0.611	+0.006	—0.9
			Average	—3.1
	Torque, Lb-Ft.			
105	138.5	.....	.....	.....
110	136.0	.....	.....	.....
115	134.5	147.0	—12.5	+9.3
120	134.0	145.5	—11.5	+8.6
125	134.0	145.0	—11.0	+8.2
130	134.0	145.0	—11.0	+8.2
			Average	+8.7

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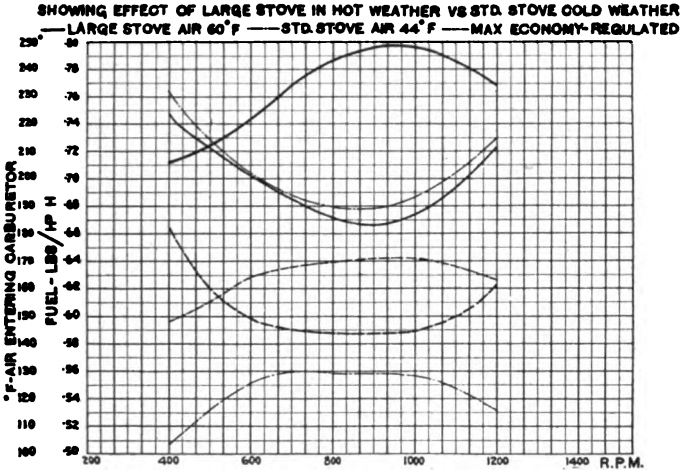

FIG. 7—EFFECT UPON THE QUANTITY OF FUEL CONSUMED PER HORSE-POWER-HOUR WITH A LARGE STOVE IN HOT WEATHER COMPARED WITH THAT OF A SMALL STOVE IN COLD WEATHER

Indications are that 102 deg. fahr. is the best temperature for the gasoline used and our thermostat was therefore set to maintain this temperature. The result was that 8 per cent or more of the fuel was saved.

VOLUMETRIC EFFICIENCY

The necessity of considering this important matter is shown in Fig. 7, which illustrates the gain of the thermostatically controlled equipment over the standard equipment. Much of this gain is due to an increase in volumetric efficiency with the cooler air. For example, at 800 r.p.m., we have with the standard equipment a charge temperature of 160 deg. and with thermostatically controlled equipment 102 deg. fahr. This is a difference of 58 deg. fahr. An approximation of the amount of expansion for 58 deg. fahr. is 12 per cent. This means that there is 12 per cent less oxygen entering with the charge under standard conditions. Assuming that the same vacuum exists at the same speed, it will be seen readily how the temperature change from day to day affects the mixture quality.

Table 4 shows that the proper temperature to insure the greatest economy is not entirely controlled by volumetric efficiency. The effect of too much cold or hot air on economy, as compared with the thermostatic control, clearly shows the necessity of finding the correct

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TABLE 4—EFFECT UPON THE QUANTITY OF FUEL CONSUMED PER HORSEPOWER-HOUR OF A LARGE STOVE IN HOT WEATHER COMPARED WITH THAT OF A SMALL STOVE IN COLD WEATHER

Speed, r.p.m.	Large Stove, Air at 68 deg. fahr.	Small Stove, Air at 44 deg. fahr.	Difference, deg. fahr.	Difference, per cent	Combined Fuel Economy, per cent
400	0.748	0.764	+0.016	—2.1	0.756
600	0.701	0.704	+0.003	—0.4	0.703
800	0.671	0.680	+0.009	—1.3	0.675
1,000	0.674	0.687	+0.013	—1.9	0.680
1,200	0.722	0.730	+0.008	—1.1	0.726

temperature. Table 5 shows the saving over combined maximum and minimum economies produced by thermostatic regulation.

CONCLUSION

This paper is presented with the idea primarily of bringing out constructive criticism. We believe that the principle of thermostatic temperature control is correct, but its detailed application is still a matter for further experiment. That there are certain periods during the year when the average internal-combustion engine functions with the minimum amount of trouble is scarcely open to argument. This is due to the fact that at that time the atmospheric temperature is right. Our idea is to select this period and to standardize it for use throughout the remainder of the year. This certainly seems to be a logical arrangement. There is nothing new in connection with the theory of temperature control. Many others have worked and are still working on this problem. Among those who have cooperated with us I wish to mention E. R. Hewitt of the International Motor Co.,

TABLE 5—SAVING IN POUNDS OF FUEL CONSUMED PER HORSEPOWER-HOUR OVER COMBINED MAXIMUM AND MINIMUM ECONOMIES PRODUCED BY THERMOSTATIC REGULATION

Speed, r.p.m.	Combined Fuel Economy	Thermostatic Regulation	Difference	Difference, per cent
400	0.756	0.664	—0.092	+12.1
600	0.703	0.598	—0.105	+14.9
800	0.675	0.588	—0.087	+12.9
1,000	0.680	0.590	—0.090	+13.2
1,200	0.726	0.622	—0.104	+14.3
			Average	+13.5

who has done much constructive work along the lines indicated. [The discussion of this paper is printed on page 123.]

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AUTOMOBILE EXHAUST GASES AND VEHICULAR-TUNNEL VENTILATION[1]

By A C Fieldner[2] A. A Straub[3] and G W Jones[4]

The data given in this paper were obtained from an investigation by the Bureau of Mines in cooperation with the New York and New Jersey State Bridge and Tunnel Commissioners to determine the average amount and composition of the exhaust gases from motor vehicles under operating conditions similar to those that will prevail in the Hudson River Vehicular Tunnel. A comprehensive set of road tests upon 101 motor vehicles including representative types of passenger cars and trucks was conducted, covering both winter and summer operating conditions.

The cars tested were taken at random from those offered by private individuals, corporations and automobile dealers, and the tests were made without any change in carbureter or other adjustments. The results can therefore be taken as representative of motor vehicles as they are actually being operated on the streets at the various speeds and on grades that will prevail in the tunnel. The information obtained can be applied also to ventilation problems of other vehicular tunnels and subways.

The vehicles comprised six representative classes which are stated, and the test conditions and methods are described in detail. The method of computing the results is outlined and the results are stated and analyzed in the text and in tabular form; a photograph and charts are presented.

The average composition of the exhaust gas, the completeness of combustion and the percentage of carbon dioxide are discussed in detail. A concise summary, in nine specific sections, concludes the paper.

The data given in this paper were obtained in the course of an investigation undertaken by the Bureau of Mines in cooperation with the New York and New Jersey State Bridge and Tunnel Commissions to deter-

[1] Published with the permission of the Director of the Bureau of Mines and the Chief Engineer of the New York and New Jersey State Bridge and Tunnel Commission.

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[4] Assistant physical chemist, Bureau of Mines Experiment Station, Pittsburgh.

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mine the average amount and composition of the exhaust gases from motor vehicles under operating conditions similar to those that will prevail in the Hudson River Vehicular Tunnel. A comprehensive set of road tests upon 101 motor vehicles including representative types of passenger cars and trucks was conducted at the Pittsburgh Experiment Station of the Bureau of Mines in accordance with a program suggested by C. M. Holland, chief engineer of the tunnel commission.

The tests were started on Dec. 1, 1919, and were completed on Sept. 30, 1920, thus covering both winter and summer operating conditions. The cars tested were taken at random from those offered by private individuals, corporations and automobile dealers of Pittsburgh, and the tests were made without any change in carbureter or other adjustment. The results can therefore be taken as representative of motor vehicles as they are actually being operated on the streets at the various speeds and grades that will prevail in the tunnel. Furthermore, the information obtained in this investigation can be applied also to ventilation problems of other vehicular tunnels and subways, several of which are under construction or are proposed in other cities of the United States.

The motor vehicles tested comprised 101 automobiles and trucks of six representative classes as given in Table 1.

TABLE 1—CLASSES OF MOTOR VEHICLES TESTED

Class	Description	Number of cars tested
1	Five-passenger cars	19
2	Seven-passenger cars	13
3	Trucks up to 1½ tons	12
4	Trucks from 1½ to 3 tons inclusive	22
5	Trucks from 3½ to 4½ tons inclusive	17
6	Trucks of 5 tons and over	18
	Total	101

Twenty-four cars were tested under winter conditions between Dec. 1, 1919 and Feb. 6, 1920; and 77 cars were tested under spring and summer conditions between March 11 and Sept. 30, 1920.

Test Conditions and Methods

In the winter series, all cars were tested under the following conditions:

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(1) Car standing and the engine racing
(2) Car standing and the engine idling
(3) Car accelerating from rest to 15 m.p.h. up a 3-per cent grade
(4) Car running 15, 10 and 3 m.p.h. up a 3-per cent grade
(5) Car running 15, 10 and 3 m.p.h. down a 3-per cent grade
(6) Car accelerating from rest to 15 m.p.h. on a level grade
(7) Car running 15, 10 and 3 m.p.h. on a level grade

In the summer series the general test conditions were simplified by omitting the racing, idling and accelerating tests in most cases as sufficient data were obtained in the winter tests to show that these particular test conditions were of minor importance in estimating the total quantity of carbon monoxide generated in the tunnel. A 6-m.p.h. test was substituted for the 3-m.p.h. test as being more representative of slow-moving traffic and a 20-m.p.h. test on a level grade was added for passenger cars. The remaining tests were the same as in the winter series. Most of the heavy trucks were tested at 6 and 10 m.p.h. only, as they could not be speeded to 15 m.p.h.

The trucks and the seven-passenger cars were tested with full load at their rated capacity and also with no load other than the two observers, chauffeur and apparatus weighing 50 lb. The five-passenger cars were tested with the light load only, consisting of three men and the apparatus.

FIG. 1—TWO AND ONE-HALF-TON TRUCK EQUIPPED WITH GASOLINE MEASURING APPARATUS AND THE EXHAUST GAS SAMPLING TUBE WHICH WERE USED IN CONNECTION WITH THE TESTS

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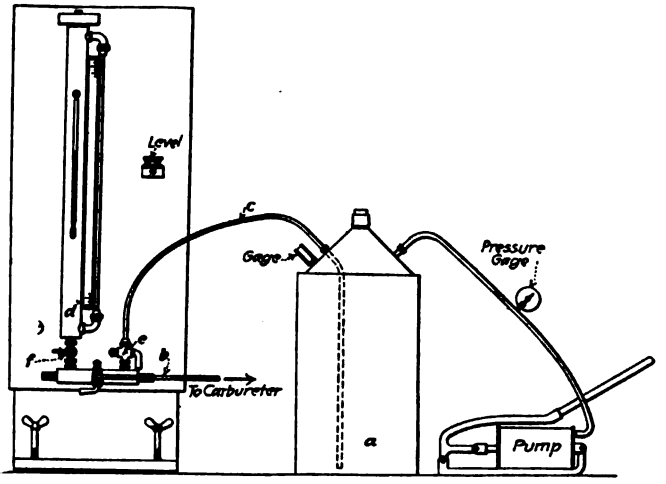

FIG. 2—GASOLINE MEASURING APPARATUS

All cars were tested in the same condition as received, without any change in carbureter or other adjustment, and with the same brand of gasoline as was being used in the car. Fig. 1 shows a 2½-ton truck equipped with gasoline measuring apparatus located in front of driver's seat and the exhaust gas sampling tube which can be seen back of cab ready for test.

The gasoline measuring apparatus shown in Fig. 2 was connected directly to the carbureter and to a reserve supply of gasoline *a*, through the copper pipes *b* and *c*, respectively. As the car crossed the boundary lines of the test course at the predetermined speed for the test the gasoline feed was switched from the reserve supply to the measuring tube *d* by closing the cock *e* and opening *b*. At the end of the test course, a reverse operation of these cocks switched the supply back to the reserve supply tank.

The exhaust gas sampling apparatus is shown in Fig. 3. A ¼-in. copper tube, *g*, bent at right angles, with the opening turned toward the engine was introduced into the exhaust pipe between the engine and muffler. The exhaust gas pressure was sufficient to maintain a rapid stream of gas through the heavy-walled rubber tube, *h*, connected to the glass tee, *i*, on the sampler board. The main stream of exhaust gases passed on through the rubber tube, *h*, and was discharged into the atmosphere

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through the water seal, *j*, thus preventing any air from being sucked back into the sample.

The exhaust gas sample was collected continuously at a uniform rate over the whole period of the test, in a 250-cc. glass sampling tube connected to the downward branch of the tee, *i*. One observer gave his entire attention to regulating the flow of a 5-per cent solution of sodium chloride previously saturated with exhaust gas from the sample tube, by adjusting the screw clamp at the lower end of the tube.

The samples were analyzed in duplicate for carbon dioxide, oxygen, carbon monoxide, hydrogen and methane

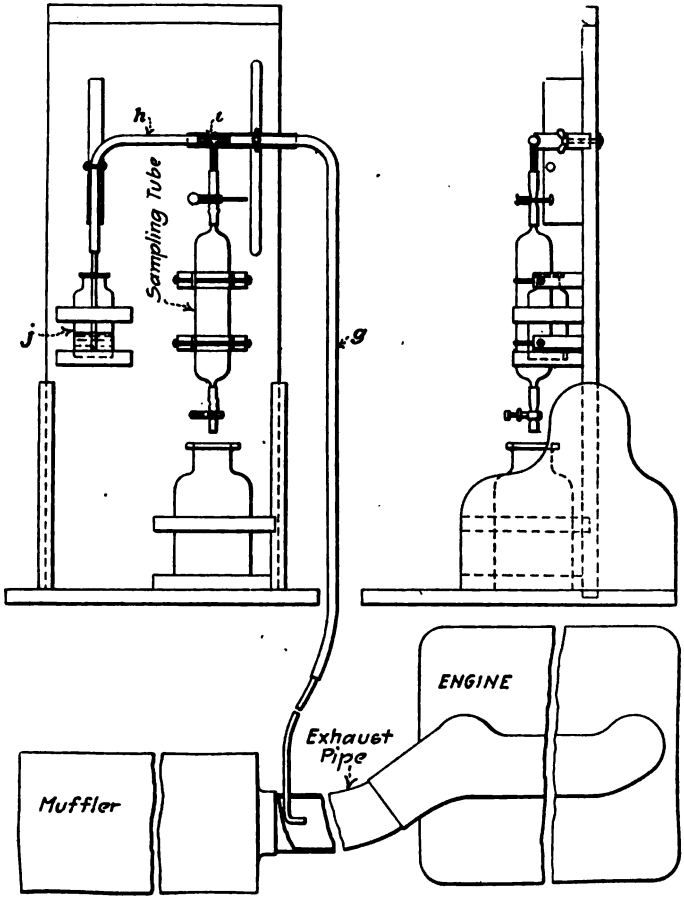

FIG. 3—EXHAUST GAS SAMPLING APPARATUS

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on a laboratory type Burrell-Orsat apparatus[6] as used in the Bureau of Mines for a complete gas analysis. The carbon dioxide was absorbed in a potassium hydroxide solution, the oxygen in potassium pyrogallate, the carbon monoxide in two bubbling pipettes in series containing an acid cuprous chloride solution and the hydrogen, methane and any residual carbon monoxide were determined by slow combustion in the presence of a hot platinum wire.

In this method of analysis any gasoline vapor and other hydrocarbons appear as methane. In other words, the analysis gives the equivalent methane value for all the hydrocarbons in the exhaust gas, and the result is correct as regards the carbon content for computing the total volume of exhaust gases from the gasoline consumption and the carbon content of the gasoline. This relation was checked to within 6 per cent by actual measurement of exhaust gas into a 50-cu. ft. container.

The determination of the gasoline vapor as methane causes the hydrogen value in the analysis to be somewhat less than its true value. This error in the hydrogen value has no effect on the calculation of the true value of the carbon monoxide, carbon dioxide and methane equivalent of the total hydrocarbons.

All the streets in the 3-per cent grade course, Fig. 4, were paved with asphalt and in excellent condition. While there was a fair amount of traffic, no trouble was experienced from stoppage by other vehicles due to the absence of much traffic on the few intersecting streets.

The Stanton Avenue portion of the level course, Fig. 5, outside of Highland Park was asphalt in good condition; the remainder of the course in the Park was macadam in rather bad condition. There were no deep holes, but the surface was worn and uneven.

Methods of Computing Results

The total volume of exhaust gases produced per gallon of gasoline consumed was computed from the analysis of the exhaust gases and the weight and analysis of the gasoline. This computation is based on the assumption that all the carbon in the gasoline appears in the exhaust gases. As a matter of fact, there is a small error due to solid particles of carbon in the exhaust and on the engine surfaces and the leakage of gasoline into the crankcase.

[6] See Bureau of Mines Bulletin No. 42 entitled The Sampling and Examination of Mine Gases and Natural Gas, by G. A. Burrell and F. M. Seibert, p. 43.

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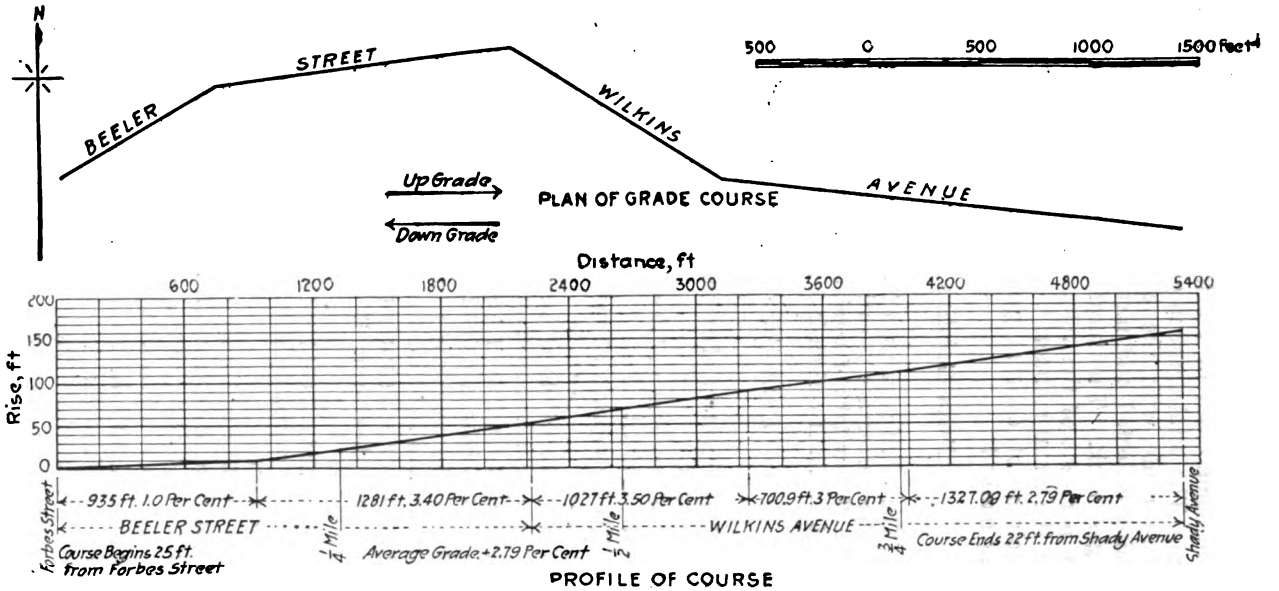

FIG. 4—PLAN AND PROFILE OF THE 3-PER CENT GRADE COURSE

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This error can be partly compensated for or even exceeded in some cases by lubricating oil burning in the cylinders. The total error is probably negligible. Some tests were made with the engine idling, the exhaust gases being collected and measured in a 50-cu. ft. calibrated gas tank. The measured volumes checked to within 6 per cent of the volume computed from the analysis in the usual manner.

The volume of exhaust gases was computed by the following method:

From Gasoline Analysis

where

a = The specific gravity of the gasoline at 60 deg. fahr.
b = The percentage of carbon in the gasoline
8.33 = The weight of 1 gal. of water at 60 deg. fahr., lb.
$8.33ab$ = Lb. of carbon in 1 gal. of gasoline (1)

From Gas Analysis

where

c = The percentage of carbon dioxide, by volume, in the exhaust

d = The percentage of carbon monoxide, by volume, in the exhaust

e = The percentage of methane, by volume, in the exhaust

0.1158 = The weight of 1 cu. ft. of carbon dioxide at 65 deg. fahr. and 29.92 in. of mercury, lb.

0.0732 = The weight of 1 cu. ft. of carbon monoxide at 65 deg. fahr. and 29.92 in. of mercury, lb.

0.0420 = The weight of 1 cu. ft. of methane at 65 deg. fahr. and 29.92 in. of mercury, lb.

0.1158×0.272[6] = 0.0316 = Lb. of carbon in 1 cu. ft. of carbon dioxide at 65 deg. fahr. and 29.92 in. of mercury

0.0732×0.429[6] = 0.0314 = Lb. of carbon in 1 cu. ft. of carbon monoxide at 65 deg. fahr. and 22.92 in. of mercury

0.0420×0.75[6] = 0.0315 = Lb. of carbon in 1 cu. ft. of methane at 65 deg. fahr. and 29.92 in. of mercury

$0.0316c \times 0.0314d \times 0.0315e$ = Total pounds of carbon in 1 cu. ft. of exhaust gas

This expression may be simplified by using the mean value 0.0315 as follows:

$0.0315\ (c + d + e)$ = Total pounds of carbon in 1 cu. ft. of exhaust gas ((2)

[6] Ratio of the atomic weight of carbon to the molecular weight of the gas.

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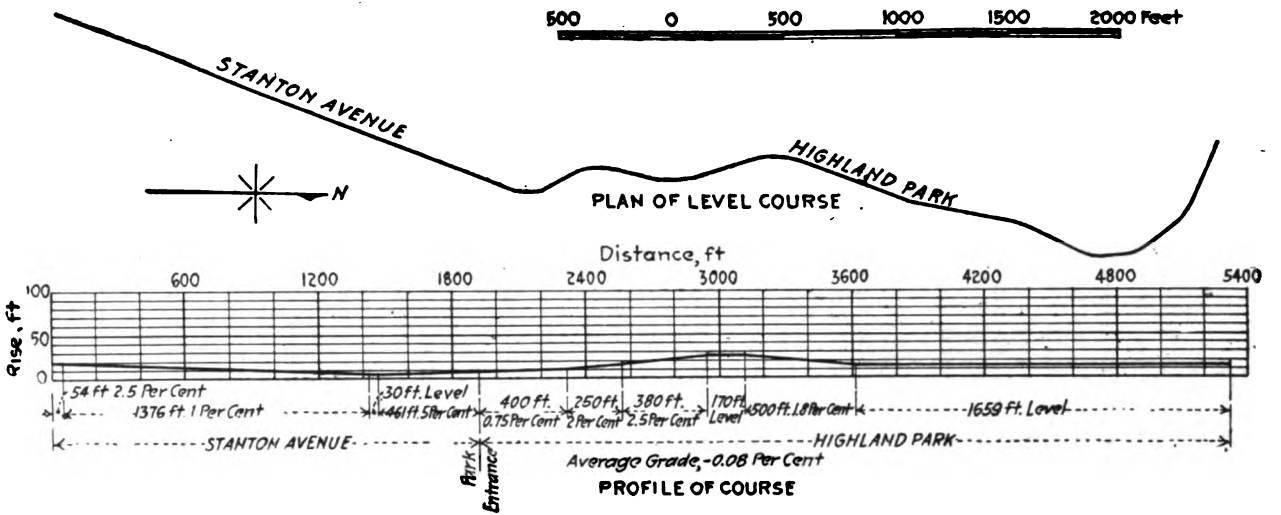

FIG. 5—PLAN AND PROFILE OF THE LEVEL COURSE

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Dividing (1) by (2)

$8.33ab/0.0315\ (c + d + e) = 264.4ab/(c + d + e) =$ The number of cubic feet of exhaust gas per gallon of gasoline at 65 deg. fahr. and 29.92 in. of mercury

The numerator of the above expression is constant for each gasoline and represents the total cubic feet of carbon-containing gases, carbon dioxide, carbon monoxide and methane, that is produced by a gasoline of the given specific gravity and carbon content. The denominator varies with each test and represents the proportion by volume of carbon-containing gases in 1 cu. ft. of the exhaust gas.

All cars were tested with the same brand of gasoline as was being used in the car at the time it was submitted for test. To avoid analyzing a large number of samples of the same brand, a large stock of each of the brands in use around Pittsburgh was obtained and carefully sampled and complete analyses of each sample are given in Table 2. The ultimate analyses, giving carbon and hydrogen content, were made by W. A. Selvig, analytical chemist of the Bureau of Mines, and the standard distillation tests and specific gravity determinations were made in the Bureau's petroleum laboratory under the direction of E. W. Dean, petroleum chemist.

Results of Tests

It is not possible to give the results of the individual tests of each of the 101 cars included in the entire investigation within the limited scope of this article. Complete results and full details will be published in a bulletin by the Bureau of Mines and a more extensive summary will be included in a forthcoming report of the Chief Engineer of the New York and New Jersey State Bridge and Tunnel Commissions. The present paper will therefore be confined to a presentation of the average exhaust gas analyses, gasoline consumption and the quantity of carbon monoxide produced and a discussion of the application of these data to the ventilation of vehicular tunnels and present-day economy in the use of gasoline.

Figs. 6, 7, and 8 give a graphical summary of the average percentage of carbon monoxide in the exhaust gas, the gasoline consumption and the cubic feet of carbon monoxide per hour for each class of motor vehicles under the various test conditions. The volume of carbon monoxide emitted is the important figure in the prob-

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TABLE 2—ANALYSES OF GASOLINE USED IN TESTS

Kind	Sample Number	Specific Gravity at 60 Deg. Fahr.	Baumé Gravity at 60 Deg. Fahr.	Unsaturation, per cent	Distillation in 100-cc. Engler Flask, Temperature in Deg. Fahr.						Ultimate Analysis	
					First Drop	Per Cent			Dry Point	Average	Carbon, per cent	Hydrogen, per cent
						20	50	90				
A	1	0.713	66.4	2.5	88	151	225	381	441	239	84.3	15.7
A	9	0.710	67.2	...	84	149	234	385	421	241	84.4	15.4
AM	2	0.731	61.5	...	93	181	266	394	451	282	84.3	15.7
AM	3	0.743	59.2	1.5	95	192	271	405	457	275	84.5	14.5
AM	10	0.748	57.2	...	86	219	277	392	435	278	84.5	15.2
G	4	0.730	61.8	2.0	104	187	259	363	414	259	85.2	14.8
G	8	0.736	60.2	...	115	194	241	352	419	253	85.1	14.7
G	11	0.747	57.4	2.0	122	219	262	374	433	275	84.9	15.3
M	5	0.722	63.9	3.0	84	167	284	432	448	277	85.3	14.7
MM	6	0.742	58.7	2.5	80	201	302	432	448	289	86.0	14.0
B	7	0.796	45.9	2.0	115	199	248	381	430	264	88.3	11.7

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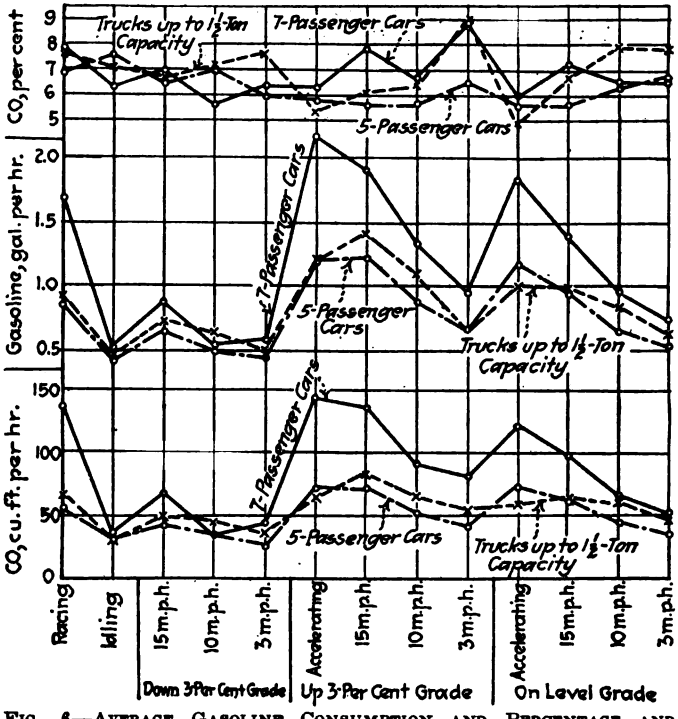

FIG. 6—AVERAGE GASOLINE CONSUMPTION AND PERCENTAGE AND QUANTITY OF CARBON MONOXIDE FOR PASSENGER CARS AND TRUCKS UNDER 1½-TONS CAPACITY TESTED UNDER WINTER CONDITIONS

lem of ventilation, as this gas is the poisonous constituent of the exhaust gases that must be diluted with air so that its concentration in the tunnel atmosphere will at no time exceed 4 parts in 10,000 parts of air.

All the results shown in the curves, except those for five-passenger cars which were tested with an average load only consisting of three men and the apparatus, are averages of two tests, one with no load other than the chauffeur, two observers and 50 lb. of apparatus and the other with a load of full-rated capacity. Figs. 6 and 7 cover winter and summer tests respectively for passenger cars and light-speed trucks. All the heavy trucks were tested in the spring and summer and are shown in Fig. 8.

It will be noticed from the plotted results that the average percentage of carbon monoxide for each class of vehicles varies between 5 per cent as the minimum and 9 per cent as a maximum, except in the heavy truck class

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where the variation is between 4 and 8 per cent, the range of variation being the same. The larger percentages tend to be produced when the engine is racing, idling or running on light load on the low gear at 3 m.p.h., and on the low-speed level grade tests for summer conditions. However, the greatest amount of carbon dioxide per hour is generated under conditions of greatest load, when accelerating or running up-grade at the highest speed. The relative quantity of carbon monoxide produced depends primarily on the gasoline consumption as shown at a glance by the similar rise and fall of the "gasoline" and "cubic feet of carbon monoxide" curves.

The average percentage of carbon monoxide under all conditions of test for each class of vehicles was, five-passenger cars 6.5; seven-passenger cars 7.2; trucks up to

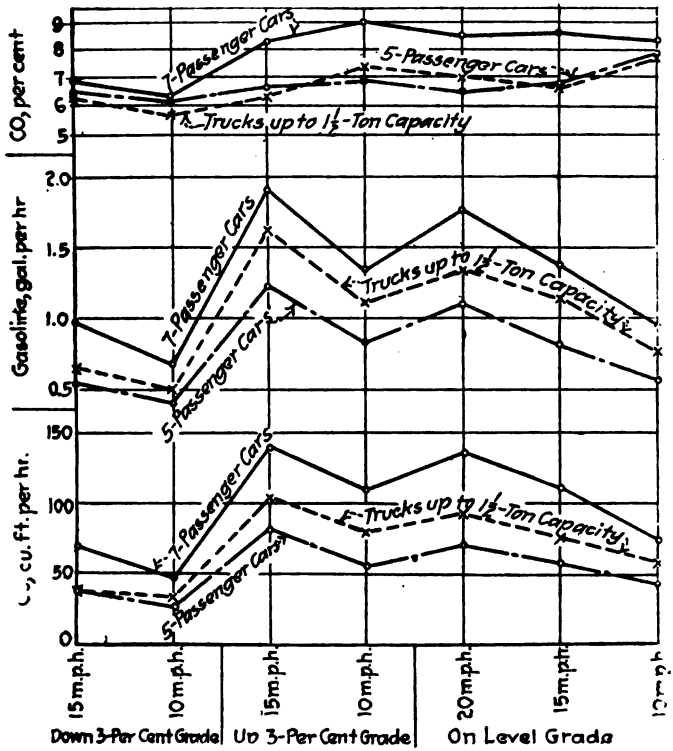

FIG. 7—AVERAGE GASOLINE CONSUMPTION AND PERCENTAGE AND QUANTITY OF CARBON MONOXIDE FOR PASSENGER CARS AND TRUCKS UNDER 1½-TONS CAPACITY TESTED UNDER SUMMER CONDITIONS

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1½ tons capacity 6.9; trucks from 1½ to 3 tons inclusive, 6.3; trucks from 3½ to 4½ tons inclusive, 6.9; trucks of 5 tons and over, 6.4. The average percentages of carbon monoxide obtained on these tests is practically the same as those obtained by Hood, Kudlich and Burrell[7] in tests of gasoline mine locomotives with carbureters adjusted for the maximum power. They found that when the maximum power was being developed the gases usually contained from 5 to 7 per cent carbon monoxide, and that the carbon-monoxide content could be increased to as much as 9 per cent without reducing the power appreciably.

These investigators have also shown that the proportion of carbon monoxide in exhaust gases varies from zero to about 14 per cent, the amount depending on a number of variables, chief of which are

(1) Ratio of air to gasoline
(2) Completeness of the vaporization and mixing
(3) Speed of the engines
(4) Temperature of the air and the jacket water
(5) Quality and time of the spark
(6) Degree of compression
(7) Quality of the gasoline or other fuel

In view of this large number of variables it is not surprising that extremely large variations in exhaust gas composition were obtained in testing motor vehicles taken from ordinary service without any adjustment prior to the test. This is particularly true since they were driven in a variable manner with foot accelerator or hand throttle by different drivers over an approximately smooth course, yet one with some rough places requiring opening and closing of the throttle to maintain a constant speed.

It is, therefore, not possible to draw conclusions on the effect on exhaust gas composition of the various factors just enumerated, except with regard to the ratio of air to gasoline or the carbureter adjustment.

A study of all the tests made shows that the variation in exhaust gas composition due to carbureter adjustment is far greater than any other factor. They do not throw much light on the advantage of any particular make or type of carbureter, nor should any conclusions be drawn as to the merits or demerits of any particular make of car. Table 3 gives a comparison of the best and poorest tests

[7] See Bureau of Mines Bulletin No. 74 entitled Gasoline Mine Locomotives in Relation to Safety and Health by O. P. Hood, R. H. Kudlich and G. A. Burrell, pp. 66 to 68.

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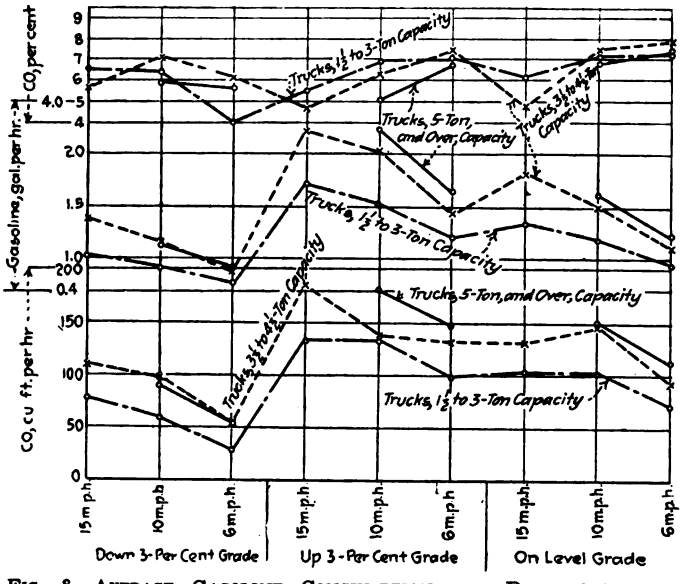

FIG. 8—AVERAGE GASOLINE CONSUMPTION AND PERCENTAGE AND QUANTITY OF CARBON MONOXIDE FOR TRUCKS OVER 1½-TONS CAPACITY TESTED UNDER SUMMER CONDITIONS

obtained on several well-known makes of passenger cars and trucks. Car No. 1 had the best gas analysis, and greatest mileage of any car tested. Car No. 44, also a five-passenger vehicle, had the poorest gas analysis and the lowest mileage in its class. Both cars operated without any apparent difficulty throughout the tests. Car No. 11 did not operate smoothly and lacked flexibility at low speeds due to the mixture being too lean. However, the mileage per gallon of gasoline was much higher than with the other cars in the same class. At speeds above 15 m.p.h. it operated smoothly and gave a good illustration of the tremendous quantity of fuel that can be saved by using lean mixtures. It should be noted that in each case the car with the leaner mixture shows the largest mileage per gallon of gasoline. The increase in mileage ranges from 36 to 106 per cent.

The effect of various carbureter adjustments on an individual car is shown in Table 4. Before putting this car through the standard series of road tests the driver, an automobile mechanic, was asked to place the carbureter in good adjustment. He set it after the engine was warmed-up to running conditions, at 1 7/16 turns of the needle valve. As shown in the table this setting

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TABLE 3—BEST AND POOREST RESULTS OBTAINED ON SEVERAL REPRESENTATIVE MAKES OF LOADED PASSENGER CARS AND TRUCKS

Car No.	Make of Car	Type of Vehicle	Speed on Level Grade, m.p.h.	Miles per gal.	Increase in Mileage, per cent.	Completeness of Combustion, per cent.	Exhaust Gas Analyses by Volume, Per Cent					Air-Gasoline Ratio, lb.
							Carbon Dioxide	Oxygen	Carbon Monoxide	Methane	Hydrogen	
1	C	Five-passenger car	15	27.30	105.8	100	13.0	2.6	0.0	0.0	0.0	16.7
9	C	Five-passenger car	15	13.26	.....	84	11.8	0.8	3.7	0.3	1.6	13.5
11	G	Seven-passenger car	15	18.61	66.8	93	9.3	5.4	1.3	0.0	0.1	20.1
10	G	Seven-passenger car	15	11.16	.....	61	7.5	2.1	9.3	1.4	4.0	10.7
84	X	¾-ton truck	15	15.39	44.5	90	10.7	3.9	1.7	0.5	0.2	16.6
76	X	¾-ton truck	15	10.66	.....	59	7.1	0.7	10.7	1.0	5.1	10.3
38	Y	3½-ton truck	10	6.55	36.2	87	12.9	0.3	1.9	0.8	0.4	13.9
57	Y	3½-ton truck	10	4.81	.....	65	7.5	0.8	10.6	1.0	4.9	10.2
44	D	Five-passenger car	15	10.26	.....	49	5.3	1.0	13.2	1.9	7.1	9.0

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TABLE 4—EFFECT OF CARBURETER ADJUSTMENT ON GASOLINE CONSUMPTION AND EXHAUST-GAS ANALYSIS

Carbureter Adjustment Needle Valve Turns	Gasoline Consumption		Exhaust Gas Analysis, Per Cent						Air per pound of gasoline, lb.	Completeness of Combustion, per cent	Remarks
	Gallons per mile	Miles per gal.	Carbon Dioxide	Oxygen	Carbon Monoxide	Methane	Hydrogen	Nitrogen			
1	0.0670	14.9	13.4	1.7	1.2	0.2	0.0	83.5	14.5	95	[8]
1¼	0.0720	13.9	12.0	1.4	2.0	1.1	0.0	83.5	14.2	85	[9]
1 1/16	0.0940	10.6	10.2	0.3	6.4	0.8	2.4	79.9	11.8	74	[10]
1¾	0.1142	8.8	6.5	1.2	11.6	1.0	6.4	73.3	9.9	56	[11]

[8] Exhaust clear; mixture too lean to operate without the use of the air choke.
[9] Exhaust clear; operation satisfactory. Air choke one-quarter on during part of the test.
[10] Exhaust slightly smoky; operation satisfactory. Car had good "pick-up."
[11] Smoky exhaust; mixture seemed too rich for satisfactory operation.

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produced 6.4 per cent carbon monoxide and 10.2 per cent carbon dioxide, a little better than the average analysis of all the cars tested. Tests were then repeated under identical conditions with both richer and leaner settings. It was found that 1¼ turns of the carbureter needle gave 12 per cent carbon dioxide and 2 per cent carbon monoxide and 31 per cent greater mileage; also the car operated satisfactorily. This car was a roadster with a four-cylinder engine having a bore of 4⅛ in. and a 4½-in. stroke. A Johnson carbureter was used and the intake air and the manifold were heated. The gasoline burned had a Baumé gravity of 66.4 deg. and a distillation of 10 per cent at 127 deg. fahr., 50 per cent at 225 deg. fahr. and a dry point of 441 deg. fahr, or an average of 239 deg. fahr. The tests were run on an asphalt pavement in good condition ascending a 3-per cent grade at 15 m.p.h.

This test is typical of the great majority of the passenger cars and trucks tested. The carbureters were invariably adjusted on the rich side for the greatest flexibility of operation rather than for the maximum economy.

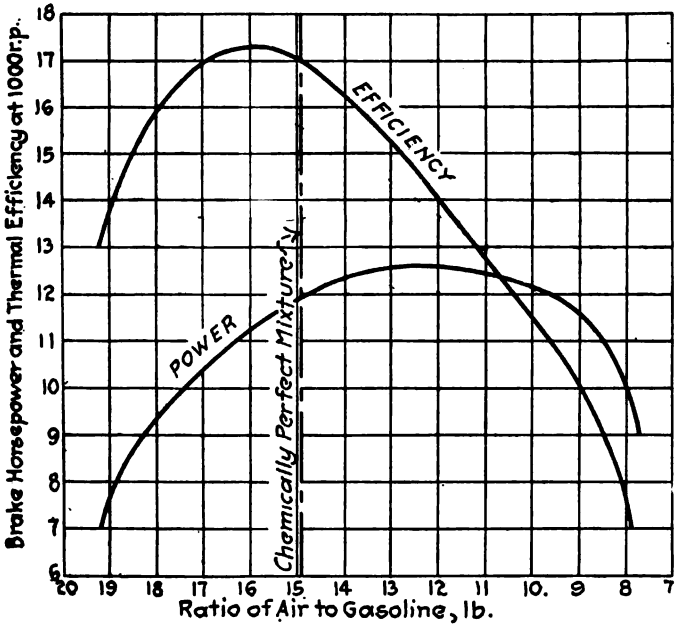

FIG. 9—CURVES SHOWING THE RELATION OF THE AIR-GASOLINE RATIO TO THE POWER AND THERMAL EFFICIENCY OF A FOUR-CYLINDER ENGINE OPERATING AT 1000 R.P.M.

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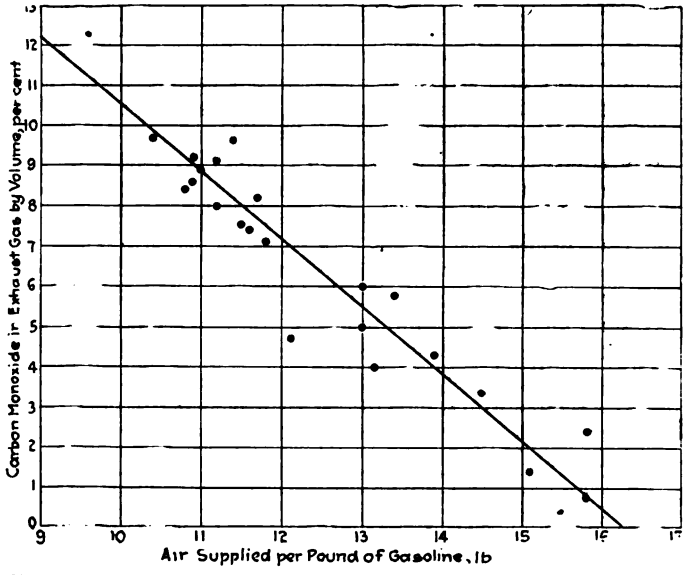

FIG. 10—AVERAGE RELATION BETWEEN PERCENTAGE OF CARBON MONOXIDE AND AIR-GASOLINE RATIO FOR PASSENGER CARS AND LIGHT TRUCKS TESTED UNDER WINTER CONDITIONS UP A 3-PER CENT GRADE

of gasoline. One pound of ordinary fuel gasoline of today such as was used in the tests just described requires approximately 15 lb. of air for complete combustion. The maximum thermal efficiency is obtained at about 16 lb.[12] of air to 1 lb. of gasoline and the maximum power with 12 to 13 lb. of air.[13] Herein lies the reason for the use of rich mixtures. The average driver demands first of all power and flexibility of operation. He sets his carbureter adjustment rich enough to give good operation with a cold engine and for slow driving in heavy traffic, with plenty of reserve power for hill climbing and bad roads. If he errs somewhat on the rich side it does not become manifest in the loss of power, but only in the increased gasoline consumption which in many instances does not concern him at all. An inspection of the average thermal efficiency and power curves of Fig. 9 shows that the proportion of air in the mixture can be reduced to 9 lb. of air to 1 lb. of gasoline with a loss of only 9 per cent in power, although the economy and the efficiency are tremendously reduced.

Fig. 10 shows the relation between the air-gasoline

[12] With this mixture the engine develops about 85 per cent of its maximum power.

[13] See THE JOURNAL, November, 1919, p. 364.

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ratios and the percentage of carbon monoxide in the exhaust gas for 23 passenger cars and trucks, the average of light and full-load tests, tested under winter conditions at 15 m.p.h. running up a 3 per cent. grade. Fig. 11 covers 20 passenger cars and trucks tested under the same conditions in the summer; and Fig. 12 shows the same relation for 54 trucks of from 1½ to 5 tons capacity and over, tested in the summer at 10 m.p.h. up a 3 per cent grade.

The air-gasoline ratios varied from 15.8 with about 0.5 per cent of carbon monoxide, to 9.0 with 13.0 per cent of carbon monoxide. The average air-gasoline ratio was 12.3 with an average carbon monoxide percentage of 6.4, practically the exact figure for maximum power. Obviously, carbureters are adjusted in practice for maximum power and not for maximum thermal efficiency and economy of gasoline.

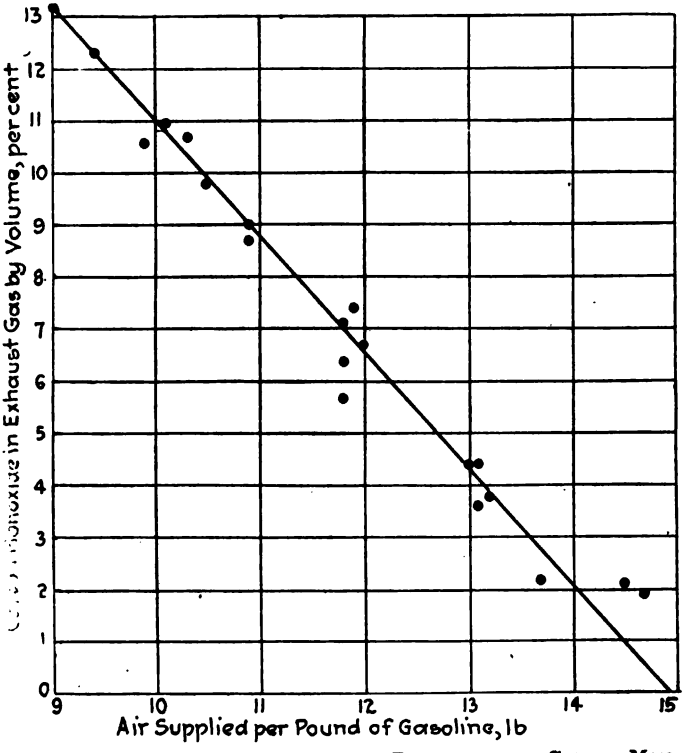

FIG. 11—AVERAGE RELATION BETWEEN PERCENTAGE OF CARBON MONOXIDE AND AIR-GASOLINE RATIO FOR PASSENGER CARS AND LIGHT TRUCKS TESTED UNDER SUMMER CONDITIONS UP A 5-PER CENT GRADE

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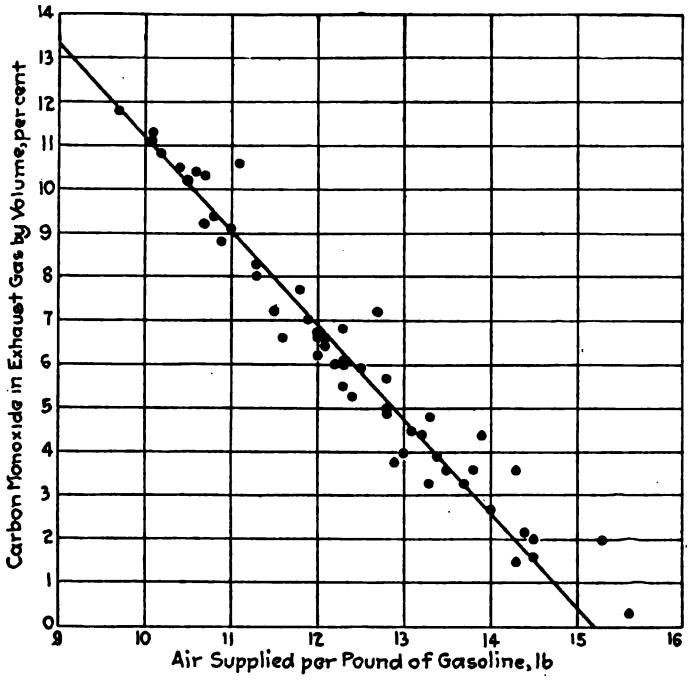

FIG. 12—AVERAGE RELATION BETWEEN PERCENTAGE OF CARBON MONOXIDE AND AIR-GASOLINE RATIO FOR TRUCKS OVER 1½ TONS TESTED UNDER SUMMER CONDITIONS UP A 3-PER CENT GRADE

The results for the 54 trucks plotted in Fig. 12 show most strikingly the lack of attention paid to economical carbureter adjustment; the air-gasoline ratios are uniformly distributed over the entire range of mixtures on which it is possible to operate the engines.

The average loss of gasoline due to the continuous operation of a car at the point of maximum power is shown in Table 5, which gives computations from average exhaust gas analyses, heat in the gasoline and heat in the unburned exhaust gas constituents.

The completeness of combustion can also be calculated with sufficient accuracy directly by weight from the exhaust gas and by volume from the gasoline analyses as follows:

In making the calculation from the gasoline analysis if we let A designate the ratio of water vapor to carbon dioxide by volume on complete combustion which is equal to one-half the percentage of hydrogen divided by one-

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TABLE 5—AVERAGE COMPOSITION OF EXHAUST GAS, BY VOLUME, FROM TESTS OF 23 CARS, AT 15 M.P.H.

	Level grade, per cent	Ascending 3 per cent grade, per cent
Carbon dioxide	8.9	9.6
Oxygen	2.3	1.3
Carbon monoxide	6.3	6.4
Methane	0.9	0.6
Hydrogen	3.0	2.9
Nitrogen	78.6	79.2
Total	100	100
Cubic feet of exhaust gases at 65 deg. fahr. and 29.92 in. of mercury	988	

twelfth the percentage of carbon and assume the heat of combustion of carbon and hydrogen as 14,540 and 62,000 B.t.u. respectively, then the percentage of heat units due to carbon or B equals the percentage of carbon multiplied by 14,540 and divided by the sum of 14,540 times the percentage of carbon plus 62,000 times the percentage of hydrogen. Similarly the percentage of heat units due to hydrogen or C equals 62,000 times the percentage of hydrogen divided by the sum of 14,540 times the percentage of carbon plus 62,000 times the percentage of hydrogen.

In using the gas analysis if we designate the volume of carbon dioxide formed on complete combustion which is the sum of the percentages of carbon dioxide, carbon monoxide and methane by D and the completeness of the combustion of carbon which is the sum of the percentage of carbon dioxide plus three-tenths of the percentage of carbon monoxide divided by the sum of the percentages of carbon dioxide, carbon monoxide and methane by E, then the equivalent volume of water vapor formed on complete combustion equals the product of D multiplied by A. Likewise the completeness of the combustion of hydrogen or F equals unity minus the quotient of the sum of the percentage of hydrogen plus twice the percentage of methane divided by D times A. Hence the completeness of the combustion of the gasoline equals

$$(B \times E) + (C + F)$$

The factors A, B and C are practically constant for any given grade of gasoline. For gasolines used in these tests these factors averaged as follows:

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Grade of Gasoline	Factors A	B	C
68-70	1.09	57	43
Motor	1.04	58	42
Benzol Mixtures	0.80	64	36

Composition of Gasoline

Specific gravity	0.713
Carbon, per cent	84.300
Hydrogen, per cent	15.700
Calorific value, B.t.u. per lb.	21,300
B.t.u. per gal.	130,000

The exhaust gas from 1 gal. of gasoline on level-grade tests contains

988 × 6.3 = 62.2 cu. ft. of carbon monoxide
988 × 0.9 = 8.9 cu. ft. of methane
988 × 3.0 = 29.6 cu. ft. of hydrogen

The total heat in the unburned gases per gallon of gasoline is

62.2 × 320[14] = 19,900 B.t.u.
8.9 × 1,000 = 8,900 B.t.u.
29.6 × 322 = 9,600 B.t.u.

38,400 B.t.u.
38,400 ÷ 130,000 = 29.5 per cent

Hence 29.5 per cent of the total heat of the gasoline goes out in the exhaust in the form of combustible gases, or in other words, the completeness of combustion is 100 — 29.5 = 70.5.

Average Composition of Exhaust Gas and Completeness of Combustion

The average percentage of unburned gases found in the exhaust of the various classes of motor vehicles tested was materially higher than was expected in view of the results of somewhat similar although much less extensive road tests reported by previous investigators. Herbert Chase[15] reported in 1914 road tests on 12 passenger cars which showed only one-third of the percentage of carbon monoxide found in the Bureau of Mines tests, although the percentages of carbon dioxide were nearly the same. A comparison of these results are given in Table 6. Ballantyne also states that

[14] Gross British thermal units per cubic foot at 65 deg. fahr. and 29.92 in. of mercury.

[15] See *The Automobile*, vol. 30, pp. 395 and 442.

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> As the result of very numerous analyses of exhaust gases from a great variety of passenger cars, I found that the percentage of carbon monoxide ranged in 1907 from a maximum of 10.3 to a minimum of 0, with an average of 3.5, while in 1908 the maximum was 8.9, the minimum 1.0, and the average 2.7 per cent. It is not too much to say that a gasoline-fed car should in respect to the emission of carbon monoxide, be hardly a worse offender than a modern locomotive, the products of combustion of which according to the very full investigation of Brislee, contain in first-class locomotive practice from 0 to 4.2 per cent of carbon monoxide with an average of 1 per cent[16]

In the Pittsburgh tests only eight out of 44 passenger cars and light trucks showed 3.5 per cent or less of carbon monoxide, and the average was 6.5 to 7.0 per cent of carbon monoxide for tests under approximately the same conditions. Undoubtedly the automobile of today has become a much worse offender on the score of discharging carbon monoxide than the coal-burning locomotive.

Figs. 13 and 14 show graphically the average composition of exhaust gas and the completeness of combustion percentage calculated from these analyses for cars and trucks under various operating conditions. Each result is an average of tests on from 12 to 22 cars. Fig. 13 shows a comparison of gas analyses of light and loaded trucks operating at a speed of 6 m.p.h. on various grades. The down-grade tests are characterized by large percentages of oxygen ranging from 4.0 to 8.5 per cent, and at the same time large proportions of unburned gases in the exhaust. Similar results were obtained on idling tests or whenever the cars were operating on a nearly closed throttle. The least oxygen and the most complete combustion was found on the up-grade tests when the cars were operating with a well-opened throttle. The level-grade tests gave results intermediate between up and down-grade tests. There is also shown a somewhat more complete combustion when the trucks are tested with a load equal to their full rated capacity.

Fig. 14 is a similar graph of average exhaust gas analyses for other operating conditions in which the light and heavy-load tests have been averaged. The greater efficiency with which a truck operates as the speed approaches the maximum for the truck is shown very clearly at the left; as for example in the 10-m.p.h.

[16] See the *Proceedings of the Institution of Automobile Engineers*, vol. 3, p. 293.

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TABLE 6—COMPARISON OF EXHAUST GAS ANALYSES OF TESTS BY CHASE AND THE BUREAU OF MINES

	Average Exhaust Gas Analysis by Volume, Per Cent					
	Carbon Monoxide			Carbon Dioxide		
	Chase	Bureau of Mines	Difference	Chase	Bureau of Mines	Difference
Car Standing—Engine Idling	2.6	7.1	4.5	8.4	7.9	0.5
Cars Accelerating from Rest to 10 m.p.h. on a level road[17]	1.9	5.5	3.6	10.1	9.5	0.6
Cars Running 10 m.p.h. on a Level Grade	2.3	7.3	5.0	9.7	8.6	1.1
Cars Running 15 m.p.h. on a Level Grade	2.5	6.8	4.3	9.5	9.0	0.5
Average	2.3	6.7	4.4	9.4	8.7	0.7

[17] In the Bureau of Mines tests the speed was 15 m.p.h.

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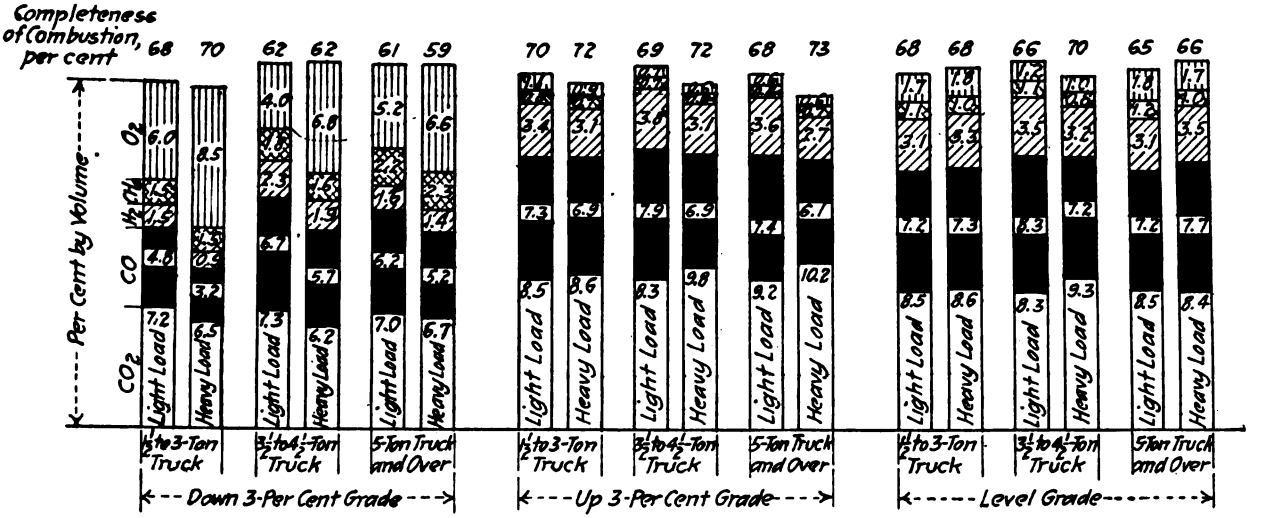

FIG. 13—AVERAGE EXHAUST-GAS ANALYSES AND PERCENTAGE OF COMPLETENESS OF COMBUSTION FOR TRUCKS OPERATING AT 6 M. P. H.

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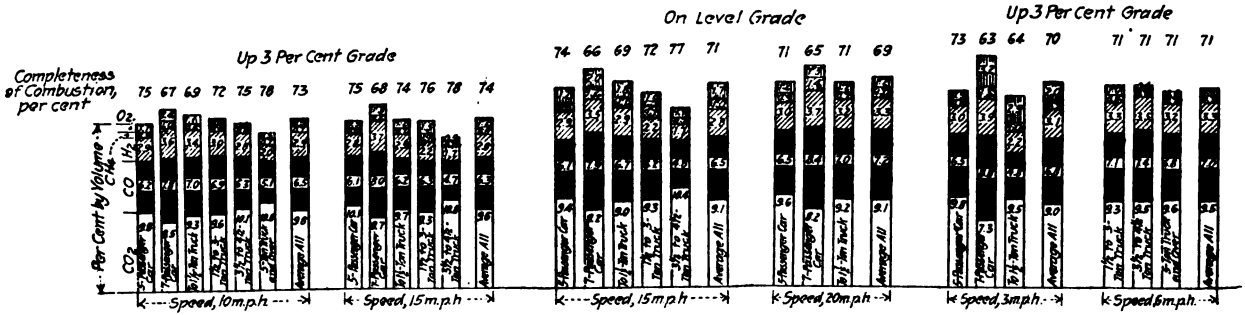

FIG. 14—AVERAGE LIGHT AND FULL-LOAD EXHAUST-GAS ANALYSES AND PERCENTAGE OF COMPLETENESS OF COMBUSTION FOR CARS AND TRUCKS OPERATING ON DIFFERENT GRADES AT VARIOUS SPEEDS

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tests up a 3-per cent grade, the completeness of combustion consistently increases from 69 per cent for light trucks to 78 per cent for heavy 5-ton trucks. The same tendency is shown in the 15-m.p.h. tests. In general the

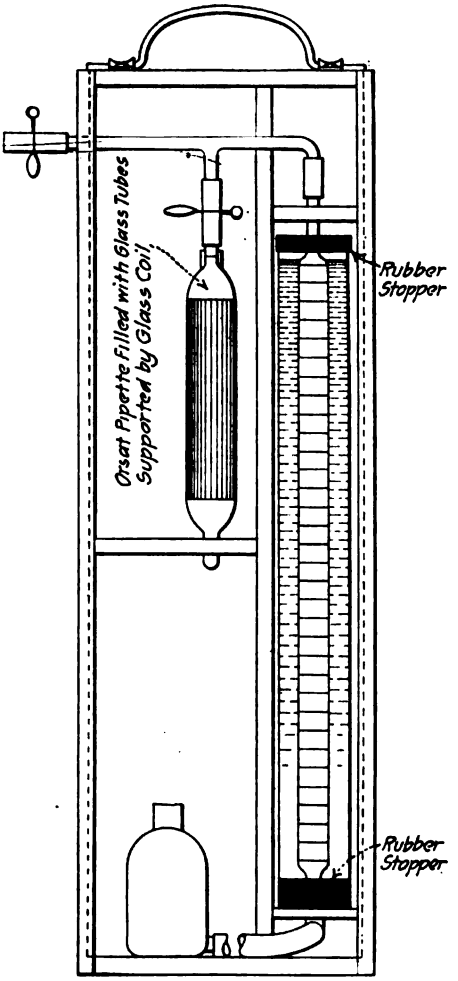

FIG. 15 — APPARATUS FOR DETERMINING CARBON DIOXIDE IN EXHAUST GASES

average completeness of combustion ranges from 65 to 78 per cent on level and up-grade tests; the general average for all cars and trucks being approximately 70 per cent.

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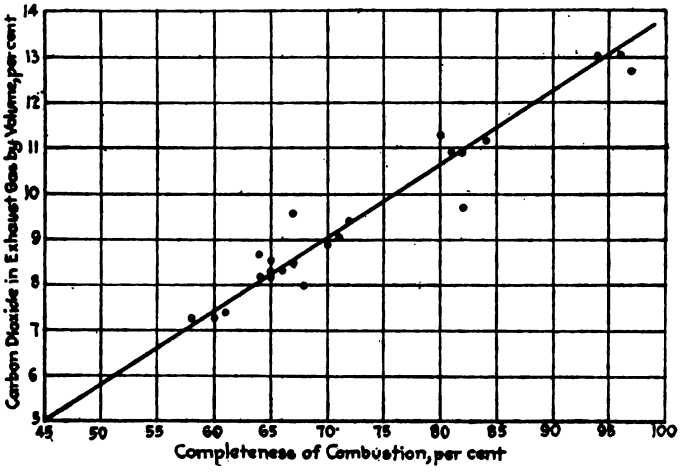

FIG. 16—RELATION BETWEEN THE PERCENTAGES OF CARBON DIOXIDE IN EXHAUST GAS AND THE COMPLETENESS OF COMBUSTION FOR PASSENGER CARS AND LIGHT TRUCKS OPERATING UNDER WINTER CONDITIONS

PERCENTAGE OF CARBON DIOXIDE IN EXHAUST GAS AND COMPLETENESS OF COMBUSTION

The exhaust gas from the gasolines used in the tests should contain from 14 to 15 per cent of carbon dioxide

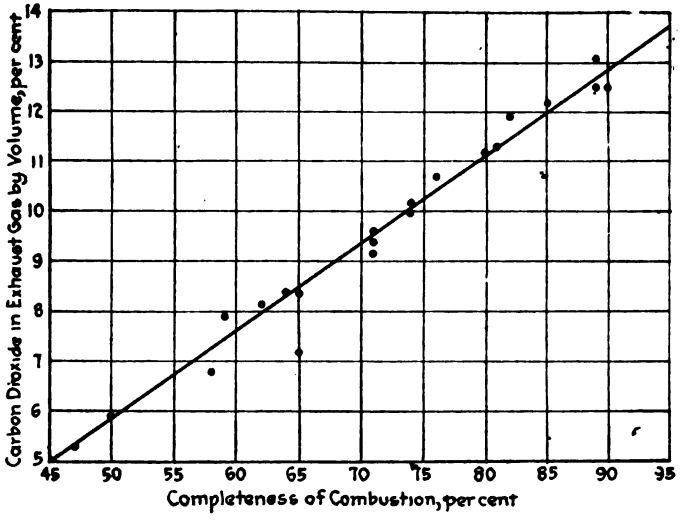

FIG. 17—RELATION BETWEEN THE PERCENTAGES OF CARBON DIOXIDE IN EXHAUST GAS AND THE COMPLETENESS OF COMBUSTION FOR PASSENGER CARS AND LIGHT TRUCKS OPERATING UNDER SUMMER CONDITIONS

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on complete combustion of a theoretically correct mixture with air, without any excess of either gasoline or air. As the combustion becomes less complete the percentage of carbon dioxide decreases proportionally. It is therefore possible to construct curves showing the relation between the percentage of carbon dioxide and the completeness of combustion. These curves can then be used in estimating the completeness of combustion from a carbon dioxide determination with a simplified Orsat apparatus[18] as shown in Fig. 15 in the same manner as the powerplant engineer checks up the efficiency of combustion in a boiler furnace.

Figs. 16, 17 and 18 show such curves constructed from tests of passenger cars and trucks running at 10 and 15 m.p.h. up a 3-per cent grade. Up-grade tests are better for this purpose than level-grade or idling tests on account of the necessity of having a steady load on the engine to minimize fluctuations in the fuel mixture supplied. These curves also serve to show at a glance the wide range of combustion efficiency found in the 101 motor vehicles tested in this investigation. Fig. 18 which represents three classes of trucks from 1½ to 5 tons capacity shows completeness of combustion ranging from 55 to 95 per cent. A little intelligent attention to carbureter adjustment with the help of some carbon-dioxide determinations should result in raising the carbon-dioxide content to above 10 or 11 per cent, which would produce a saving of at least half of the 30 per cent of the heat in the gasoline now escaping in the exhaust gases as carbon monoxide, hydrogen and hydrocarbons. A change of carbureter adjustment to this extent would not impair the flexibility of operation. It is of course well known that theoretically perfect mixtures with absolutely no unburned gases in the exhaust do not give flexibility of operation on account of the lower velocity of flame propagation. However, good operating characteristics are readily obtained with 12 to 13 per cent of carbon dioxide in the exhaust gas which represents 85 to 90 per cent completeness of combustion.

SUMMARY

Road tests were conducted at Pittsburgh on 101 passenger cars and trucks of various capacities to determine the amount and composition of the exhaust gas discharged under the various conditions of speeds and

[18] See Bureau of Mines Bulletin No. 74 entitled Methods of Analyzing Exhaust Gases, by G. A. Burrell, p. 73.

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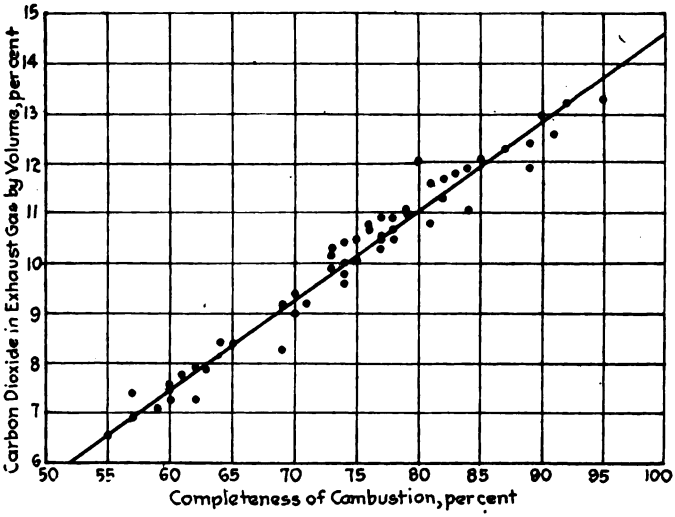

FIG. 18—RELATION BETWEEN THE PERCENTAGES OF CARBON DIOXIDE IN EXHAUST GAS AND THE COMPLETENESS OF COMBUSTION FOR TRUCKS OVER 1½-TONS CAPACITY OPERATING UNDER SUMMER CONDITIONS

grades that may prevail in vehicular tunnels, and especially the particular conditions of the Hudson River Vehicular Tunnel. The results of these tests have shown that

(1) Automobile exhaust gas consists of carbon dioxide, carbon monoxide, hydrogen, hydrocarbons, oxygen, nitrogen and water vapor, the relative proportion of these constituents varying greatly in the exhaust from different engines, depending on carbureter adjustment, degree of atomization, compression, etc.

(2) The important constituent of exhaust gas as regards tunnel ventilation is carbon monoxide. Physiological tests on exhaust gas reported by Dr. Yandell Henderson show that the maximum allowable concentration of carbon monoxide in air for 1-hr. exposure is 4 in 10,000.

(3) The percentage of carbon monoxide for the various individual cars varied from 0.5 to 14.0 per cent, passenger cars and speed trucks on level grades at 15 and 20 m.p.h. averaging 7.0 per cent and 1½ to 5-ton trucks at 10 m.p.h. averaging 7.3 per cent. Seven to 7.3 per cent of carbon monoxide corresponds to an air-gasoline ratio of 11.8, a slightly richer mixture than is required for developing the maximum power. The maximum power mixture ratio is 12.5; the maximum thermal efficiency mix-

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ture ratio is 16.0 and the complete combustion mixture ratio is 15.0

(4) The larger percentages of carbon monoxide are produced when the throttle is nearly closed, as when running down-grade or the car standing with the engine idling. The largest quantity of carbon monoxide is produced when the gasoline consumption is greatest, as with cars accelerating or running up-grade at maximum speed

(5) Completeness of combustion varies directly as the percentage of carbon dioxide in the exhaust gas and inversely as the percentage of carbon monoxide. For the same carbureter adjustment in a given engine combustion is most complete with the engine operating under full load at its normal speed. However, the completeness of combustion of different cars varies greatly under the same condition of test. The primary factor in causing this difference appears to be the carbureter adjustment. The total range for different cars was 50 to 95 per cent. The average for all cars was about 70 per cent

(6) The combustible gas in the average automobile exhaust from 1 gal. of gasoline contains nearly 30 per cent of the total heat in the original gasoline. Thirty per cent of the 4,000,000,000 gal. of gasoline consumed in 1919 amounts to $400,000,000, with gasoline at 33 cents per gal. Careful carbureter adjustment should result in saving half of this amount

(7) The great majority of motor cars and trucks are operated on rich mixtures suitable for maximum power but very wasteful from the standpoint of gasoline economy.

(8) The average motor-car carbureter is set for winter operation and is not changed in the summer, as shown by the higher percentages of carbon monoxide and the richer mixtures found in the summer tests

(9) The public should be impressed with the saving in gasoline resulting from the use of lean mixtures. If the builders of automotive engines would provide for the installation of a small gas sampling tube in the exhaust pipe of engines, especially on trucks, it would tend to introduce the use of carbon-dioxide determination for the control of carbureter and other adjustments. Taxicab and trucking companies could well afford to employ a chemist to make regular control tests. He could save his salary many times over, in cutting down the gasoline consumption

[The discussion of this paper is printed on page 123.]

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THE BODY ENGINEER AND THE AUTOMOTIVE INDUSTRY

By Kingston Forbes[1]

The field of body engineering is broader than it is ordinarily considered to be; the author's intention is to bring to the attention of the automotive industry the breadth and scope of body engineering and outline the way this side of the industry can be considered and developed.

After describing the body engineer's position, the author then discusses at some length the conflict between art and economy in this connection. He classifies a body-engineering department under the six main divisions of body construction, open and closed; sheet metal, body metal, fenders, hood, radiators and the like; trimming; top building; general hardware; painting and enameling, and comments upon each. Following this he elaborates the reasons for need of attention to details in body designing and mentions the opportunity there is at present for bringing the materials used in body construction to definite standards.

In choosing the title of this paper it was hoped that a note could be struck which would bring to the attention of the industry the breadth and scope of body engineering and outline the way this side of the industry can be considered and developed. Body engineering must, of course, depend on mass production or big business for its greatest encouragement. In small-scale production small items can be handled very easily, but in large production they are of tremendous importance. If 1000 cars are scheduled to be made in a day and a shortage occurs in one of the smallest items, the entire production may be held up, incurring a loss of thousands of dollars. This emphasizes the importance of every detail in large business in a way that no one can fail to grasp. For instance, if a change in design could be made by the body engineer that would permit cutting the leather for the trimming to 15-per cent waste instead of 20, a saving of $1,000 and over per day would be made in a daily car production of 1000. In a small shop or custom shop a few feet of leather more or less would not make much difference.

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[1] M.S.A.E.—Assistant body engineer, Buick Motor Co., Flint, Mich.

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The field of body engineering is broader than it is ordinarily considered to be. The body engineer's relations to a body-building plant, large and small car plants and a custom shop, demand different classes of engineers. In the main the body engineer is responsible for the external appearance of the entire car. If it is a custom-built job, a preliminary sketch of the complete car is made, and very often this is all the body builder, top maker and trimmer have to work on; the car is made to look as much like the sketch as possible. A body plant very often submits designs for a complete car, but generally has only the body to build. To work out his ideas or combination of ideas the body engineer of the small plant relies to a great extent on the companies which build his bodies. In a large plant where bodies and all other metal parts are made, the body engineer has to consider the manufacturing details involved in all parts that he designs. There is a distinct difference between the mechanical side of the automobile and the general appearance or the artistic side. One would not ordinarily combine the story writer and the illustrator in more than a cooperative spirit. The success of the story does not depend upon the illustrations, or vice versa. But having a good story properly illustrated gives a wider field for its sale. So it is with a car; the mechanical condition and limitations have to be taken in hand by the body engineer. As a first qualification the car must be artistic. This is demonstrated by the 1921 cars. The body engineer of a company specializing in custom work must apply artistic principles in every body he designs; each car demands individuality and draws heavily on his power of creation. In the case of large production, a body designer has to satisfy 100,000 people with perhaps one model. We know that the tastes of 100,000 people are not all the same, although some of our movie stars have an unlimited following. The design for the 100,000 is not the most stylish design, but the one that will be most acceptable to the majority.

Customers often say that a given car does not quite suit and specify some favored characteristic, but few will agree on any specific design. If, however, a car of established popularity is shown, practically all will be satisfied with it. The point I wish to make is that simplicity of design and absence of jarring notes can be evolved only by painstaking effort. The layman cannot appreciate the work behind the smoothly finished

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product. The effort is not evident as with carvings and intricate embellished curves on historic buildings and churches.

Conflict Between Art and Economy

Art as applied to an automobile has to be manifested in the arrangement and shaping of sheet metal or other units on frames. Whether the result required can be attained in economical manufacture has to be considered. The production of one thousand or more cars a day does not permit fancy hand decoration or carvings. Art has to be satisfied by huge presses and metal-forming machines. To achieve results, the practical sense of the body engineer must be as keen as his artistic ability; they must be coordinated to avoid disappointment. While there are definite conceptions upon which the artist bases his work, his success does not depend upon geometrically arranged lines, nor can the composition of his pictures be worked out with a slide rule. The mechanical side of the car is amenable to slide-rule practice, but the body lines are not. This is one reason body engineering has an indefinite position in the industry.

In large production it is not possible to control the metal parts in very fine degree, owing to variation in the grades of metal and the fluctuations in the operation of the presses. The upholstering, top design and painting, including enameling, all have a bearing on the final results. The main trades involved in body engineering are wood-working, sheet-metal working, metal machine-work, brace and hardware trimming, top building, painting and enameling. The body engineer should be familiar with all these trades. None of them can be learned by correspondence courses. In fact, there are practically no schools or instruction books covering the modern phases of the work.

A body engineering department can be classified in six main divisions.

(1) Body construction, open and closed
(2) Sheet metal, body metal, fenders, hood, radiators, etc.
(3) Trimming
(4) Top building
(5) General hardware
(6) Painting and enameling

All the arts pertaining to the six divisions dovetail into one another and must have weight in the preliminary

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design. For instance, the radiator and hood can be considered the starting point for the body design; when these are established the main body construction is worked out from the dash or cowl-line back. The exterior lines of the body must be pleasing to the eye; at the same time the passenger capacity has to be ample and the comfort adequate. Satisfactory trimming has to be arranged for. Comfort depends upon leg-room, body-room and positions and well-arranged cushions and back springs with soft padding with suitable cloth, plush and leather covering. Passing on to the top, if it is an open body, the lines and windshield must be considered to permit a top to be made that will give proper protection and at the same time be pleasing in appearance and of course harmonize with the rest of the car.

The fenders and side aprons and radiators and mud-pans can add or detract much from a car's appearance, and must be worked out to blend with the other larger elements in car craftsmanship. Under general hardware come numerous small parts such as window regulators, door-locks, windshield hinges, not very large in themselves but important in providing ease of operation and satisfactory service. What is more annoying on a car than defective locks, rattling doors and hard-working or leaky windshields? Last but not least comes the painting. When this is done properly it adds tremendously to the final results. The panels, molding and corners should be made so that painting will be simplified. Sprays and flowing operations are used in modern mass-production methods; bad corners, moldings and holes will interfere seriously with the paint and cause varnish and dirt runs. If it is planned to have molding in color different from that of the main panels, it must harmonize and not produce discordant lines.

Need for Attention to Details

I have endeavored to indicate the breadth of the body engineering field. As the production increases, accuracy in details becomes more and more necessary. An organized department is required to handle this work. The grouping previously referred to can be made into department divisions, controlled by a separate engineer if the volume of work warrants it, with one or more men to keep the work in progress. Also a general drafting force with chief draftsman and checker are required.

Modern accounting and production demand minute in-

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formation about every piece that goes to make up a car, and this entails a great amount of detail drafting work. Every piece of wood, top and side-curtain material, reinforcement, ragboards and wadding, trim material, leather, artificial leather, binding; ounce of hair, tacks and nails and every screw, nail and piece of hardware mean that engineering information is required with the blueprints and specifications. The old method was to make paper patterns of all of the parts and let the manufacturing departments control their own work; whenever duplication of parts was required, additional paper patterns were made and sent out. Long ago it was found that no progress could be made in manufacturing without proper engineering records and blueprints.

I venture to say that there are several modern automobile plants that have no definite engineering control of the material purchased and fabricated in the groups outlined. This material runs into millions of dollars per year.

While the art of coach-building is as old as the ages, it was brought to a manufacturing basis only a few years ago when buggy production hit its high mark. The advent of the automobile brought entirely new problems. The automobile body engineer is a recent recruit in the engineering profession. His importance can be measured by his designs and by his control of body materials and their fabrication. It is not sufficient that a beautiful and readily marketable design be produced; it must be possible to make it economically and without waste of material. The future holds big opportunities for the body builder and engineer. Competition will be keener than ever, not only among the body builders, but among the car builders. The automobile competition will be the body engineer's opportunity. With the stabilizing of chassis construction, the external body and allied construction will become one of the biggest factors in marketability and the stimulating of sales.

There is opportunity for bringing the materials used in body construction to definite standards. A few of the items that could be considered seriously in this connection are lumber specifications, cushion-spring wire, fabricated cotton hair, burlap, imitation leather, top materials, webbings, closed body and windshield glass, automobile hardware, body bolts, curtain fasteners, bow sockets, top hardware, bow bendings, back curtain lights and door-handles.

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THE DISCUSSION

L. L. WILLIAMS:—Body engineers have from time to time had occasion to look for certain body-engineering standards which they find are not available in the S.A.E. HANDBOOK. This applies to specifications for lumber, aluminum, sheet steel, hair, cotton fabric and other body-building materials. It seems to me there is a great need to issue, for the benefit of body engineers, something stable which we can use as a standard when we talk with these manufacturers who have been using their own judgment as to selling us what they chose and what their selling organization has said was the right thing for us to use. I think the Society ought to specify something that body engineers want to enable them to check against what the manufacturers want. Let us get some real engineering into body designing and actually set down something that we can go by. For instance, let us find out the tensile strength of cotton and other fabric for upholstery purposes and determine how long it can be expected to stand up. That is one way in which we can put this thing up to the manufacturers and make them realize that we have specific requirements. The same thing applies to sheet steel. We ought to know what it will actually stand, what the ductile quality of a piece of metal is. There are many good men here who have the information, but they seem timid and afraid to stand up here and make definite statements. They ought to stand up and make statements of fact and call everything by its right name, so that we can get body engineering on a basis equal to that of chassis engineering.

G. C. BAKER:—Perhaps the body engineer or designer is somewhat at fault himself. We have a Society of Automotive Engineers, and I think we have been a little slow about getting into it and pulling together. I joined the Society some time ago in the hope that the body engineers would get together on bodies in the same way that the chassis engineers have got together. The thing for the body engineers to do is to hoe their own row and not find fault with what the chassis engineer has put up to them. One of the speakers brought out the point that the engineer has suspended the engine on a three-point support, so that the engine would not be strained, and regretted the fact that this puts it up to the body designer to mount the body so that it will withstand the road jar. As body engineers we should take up our end of it and suspend the body on three points or in some different

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way if necessary. One speaker mentioned the fact that some method has been tried out of supporting a body so that it will swing free on a frame. These little points lead me to believe that perhaps we, as body engineers, have been as much to blame as some of the people who have put it up to us; so, let us pull together.

E. J. CONNOLLY:—When was the all-steel body first designed?

GEORGE E. GODDARD:—I cannot tell exactly. My first introduction to it was with Dodge Bros. Their first all-steel body was then in use. The first ones used in quantity production that I knew anything about were made by this company.

GEORGE W. KERR:—The first all-metal body that I ever saw was made about 1902. There were no trimming strips on the body. The trimming was all made so that it clinched under channel-iron frames.

SCHOOLS OF BODY DRAFTSMANSHIP

The principal thing that I wished to bring up in taking part in this meeting, is to make a plea for the establishment or re-establishment of the technical school of body draftsmanship. The Carriage Builders' National Association established a technical school in New York fully 25 years ago and operated it until the automobile superseded the carriage. For a brief time it was supported in some degree by this Society and its predecessor, but it was abandoned. It ought to be reinstated. There should be such a school available at a central point somewhere in the United States, where body design and body draftsmanship can be taught and developed.

In the old days the instruction in body draftsmanship was too much along an individual line. That was all right so long as it applied to carriages; when the carriage draftsmen began to go into the automobile shops, there was such a divergence in their methods from the standard methods in vogue in the drafting-rooms that it was difficult for them to become recognized as regular draftsmen. In almost every case they had to spend more or less time learning the technique of mechanical draftsmanship, so that their drawings, when turned over to the pattern-room and to the engineering departments, would be intelligible to the pattern-makers and the engineers. The line of instruction in the technical school I recommend should be designed to bring body drafting more into line with regular mechanical drafting, so that this trouble can be avoided. We have had to teach almost every body

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draftsman how to make mechanical drawings. There is a very essential difference between body drafting and regular engineering drafting. In almost every case the straight edge and compass will fill all requirements in mechanical drafting, but the essential basis of art in body drafting is free-hand lines that are not capable of being made with a straight edge or a compass. I wish to start a movement to get a technical school established at some central point, where this work, so worthily and so faithfully carried on by the Carriage Builders' National Association, can be carried on by the automotive industry.

CHAIRMAN WALL:—There is a great need of instruction of this kind. Could any of the present engineering technical schools be interested in the starting of such a department? Would that answer as well and could we get them to take sufficient interest to install some such course?

H. J. WARREN:—I studied in a carriage builders' school some 35 years ago in New York, but when I came to build automobiles I had to learn mechanical drawing and engineering in addition. Even that was not sufficient. I have attended the two schools combined and even now find something lacking in my own knowledge and experience. A new school must be established. In the kind of school we need to have established, carriage drafting, designing, engineering, foundry practice, die-working and mechanical drawing must be taught.

In the designing of cars the chassis engineers have ignored the body engineers completely. They have furnished us with handicaps as severe as any architects could have encountered. We have made a few successes, but we have had a hard fight. When the chassis engineers begin to cooperate with us in building chassis, we will begin to see results. To produce a set of dies like the ones shown here requires a fortune. It cannot be done except in quantity production. How are small producers going to come in? They cannot do it; they have neither the time nor the money. When the chassis engineers accept the body engineers on an equal footing and allow us to work with them, we will get results. That ought to be the result of this meeting.

S. J. HOWELL:—In regard to the question of establishing a body engineering school in a college, I am from a scientific school. We have what is termed the automotive engineering course. Our work in that line is looked down

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upon by the university; it is considered as being too specialized. The idea of the college is to give a course that will enable one to tackle the problems of engineering, but not to give the engineering problems themselves. On that account it seems to me that the scientific schools would not be willing to allow the establishment of a body-engineering course. They seem to think all the work should be entirely theoretical. If the body designers say that they want men trained in this line, the colleges might reconsider and turn out men who have some practical and general ideas of automobile engineering.

G. H. WOODFIELD:—I have experienced the same condition. I went through a school in New York City. The most successful designs I have produced have been those in which the chief engineer met me half way.

COOPERATION PRECEDENTS

C. S. RICKER:—One subject ought to be emphasized to body engineers who are not familiar with the work the chassis engineer has accomplished through the medium of this Society and the cooperation of its Sections. For example, in regard to the engine-starter and electric lights on the automobile, about 8 years ago there was just about as much cooperation between the men who were trying to find their way into the electrical equipment business and the chassis engineer, as body engineers seem to find with the average chassis engineer of today, although the two latter classes have been in contact much longer. The former two have come very close together and solved a problem that in many ways was equally difficult, if not more so, because the electrical men knew practically nothing about their own problem of handling the low-voltage electric current that was demanded on the automobile. We had in that instance a case of cooperation that has led to the present successful development in electric lighting for motor cars.

Another case of the same kind of cooperation is to be found now between the fuel men and the chassis engineer. It would be practically impossible to make a car perform properly if the chassis engineer did not concede something to the carbureter man and if he, in turn, did not give something to the chassis man to obtain an operable utility for public use. In the case of the body engineer, I think he will find that he can get close cooperation from the manufacturer. Many of the engineers who have appreciated the body-builders' problem are designing

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deep chassis frames now. On at least 10 cars, within the last 2 years, the depth of the chassis frames has been increased from 1 to 3 in. to provide a more adequate support for the body. Again, the chassis engineer has been widening the frame and locating the springs beneath it, so that the channels would not twist with the spring action, thus providing a solid foundation upon which to place the body. In the support of the body the chassis engineer must have a kick-up in the frame at the rear end, to allow for spring action and to provide the easy riding qualities that are demanded by the public. The cushions alone are not sufficient for this purpose. The carrying of a body sill over the frame kick-up also weakens the back end of the body. Efforts therefore were made to avoid these difficulties. For example, I have seen one frame on which the sills are absolutely straight, run along the side of the kick-up and are supported on brackets attached to the frame side-rail. Working this problem out in another way also helped the body engineer. This sill construction was made necessary by the manufacturing methods in the plant where I saw it. They did all their own painting and carried all the bodies through the ovens on flat chain conveyors. They also flowed all the color, prime and varnish, over their bodies. They found that with the kick-up it was difficult to handle the body on conveyor mechanisms without special supports and that was one of the chief reasons why they went to a straight flat sill the entire length of the body.

M. W. GAFFNEY:—I have had some experience within the past year in body designing and mechanical drafting. I find no difficulty whatever in breaking in good draftsmen for body drawing. I am willing to instruct these young men and they learn very quickly. I see no reason why we should be worried about that. A man with brains ought to be able to take up such work quickly. I see no reason for establishing a school. Such a school was all right in its day, but it has outlived its usefulness.

MR. GODDARD:—In one case where we had 23 different types of body, the drafting was a large problem. We subdivided it. The full-size draft from which the body was made was handled in a separate drafting department. It had its own sample body shop in which to make samples and test out the drafts before turning them over to the production department. We also had another division of the body-drafting department which took care of all hard-

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ware and such units as folding seats, foot-rails, robe-rails, hinges and locks. That class of work can be handled by mechanical draftsmen very well. The mechanical drafting division, as it might be called, also took care of the rear fenders, which are properly part of the body work. In our wood-frame construction we used the metal wheel-housing, which was handled by the mechanical drafting department, as well as the windshield and top parts such as sockets and the like. In order for them to work with the drafting department which made the full-sized drafts of the body itself, we found it necessary to make what we called a master layout. This was a special drawing or drawings showing the surfaces to which they had to work. For instance, we would take a portion of the body from the rear door-hinge pillar back to the center of the tonneau, working of course from the same points originally established on the master full-sized draft. We would lay out the shape, for instance, of the wheel-housing line; in other words, the line which the rear fender must fit up to. In that way the mechanical drafting division could work out their detailed drawings of the metal wheel-housings, seat panels and the fenders, such as a pattern-maker and the machine shop would use. When the wheel-housings and fenders were assembled in the body, they fitted perfectly. The whole automobile body subject is a complex one, but it merely requires organization and subdivision. I have outlined the way the problem can be handled where bodies are designed and built in the same plant as the chassis. The idea of dividing the work and making the men specialists in their particular line of work may be helpful.

MR. KERR:—Some remarks have been made that I dislike to have remain as the last word on the matter of a body-engineering school. The typical attitude of the mechanical engineer toward body designing and the body engineer was expressed; it is that anyone can do it. We who are regular body designers have spent our lives in acquiring something that the ordinary mechanical draftsman does not have an opportunity to work on. One of the qualifications for doing a poor job and a cheap one is ignorance of the subject. If we want to make the cheapest thing that can be made, the less we know about that thing the better, because our ignorance will lead us just a little way and there we will stop. The fact that all of the well-known carriage designers were drafted into the automobile business, after the regular automobile designers had come to realize that they were

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deficient on a certain subject, shows that the automobile-body draftsman and designer had something that they did not have. It is to perpetuate that something and carry it on, and make body draftsmanship a desirable thing to learn and a thing that will be continued, that I advocate the establishment of a school of body design.

KINGSTON FORBES:—Laminated wood or wood-panel bodies require more time to make than the present style of wood-frame and metal-covered bodies. They require also equipment which takes up much space that would be out of the question in large-production manufacturing. This point is demonstrated by the manufacturer of the laminated wood roofs for closed bodies which require special equipment and large presses.

With reference to the ancient art of carriage building mentioned by Mr. Moskovics,[2] very little of the 400 years of precedent is exemplified by the modern motor-car body. For example, the all-steel enameled body is entirely a modern conception. In the last few years almost every form of construction that could be considered for an automobile body has been tried out and, so far, the solid-unit construction is found to be the most widely practicable and this is a combination of metal and wood. The real body development has been in the closed-car body, and this cannot be built up of different sections very conveniently. The closed car was primarily built for city use, but today the owner would be surprised if he could not drive his closed car 40 m.p.h. or over. If it rattles or creaks, he turns it over to the shop.

A. F. JOHNSON:—The art and craft of vehicle body building, it is actually much more than 400 years old. In the World on Wheels, page 211, we read that

> As early as 1294 A.D., by an ordinance of Phillip the Fair, of France, for suppressing luxury, citizens' wives were forbidden the use of carriages, under heavy penalties; but this restriction was not long continued.

Further, quoting from Rondo, page 457,

> Up to the time of Charles VII, of France, in 1457 A.D., carriages were set directly upon the axles; but in that year Ladislaus V, King of Hungary, gave a coach to the French Queen. This coach was much admired by the Court and by the people of Paris.

This presumably was because the coach was suspended on leather straps, as steel springs were then unknown.

[2] See page 272.

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INVESTIGATIONS OF ROAD SUBGRADES

By A T Goldbeck[1]

The problem of the subgrade is evidently that of finding what causes certain kinds of subgrade material to be soft and of very low bearing value and, having ascertained this, to determine what means must be employed either to remedy the condition of the subgrade or fit the design of the road surface to the subgrade. The author considers the mechanics of the problem and some of the various factors involved in producing an unstable condition in the subgrade.

The paper is illustrated with charts plotted from data obtained relative to the bearing power of soils, intensity and distribution of pressures, various forms of road construction in connection with the principles underlying the drainage of subgrades and impact tests. The road tests made at Camp Humphreys are described. Soft subgrades are considered at length; the drainage problem in general is discussed and results of laboratory investigations of subgrades presented. Bearing value tests of soils and drainage investigations are next considered specifically.

Although road engineers have long realized the necessity for properly supporting the road surface, only in the past few years has there been a more general recognition of the value of a close study of the subgrades of roads. Let us review some of the conditions that have forced upon us the desirability of looking into the subgrade; then we shall have a better understanding of just what we mean when we speak of the "subgrade problem."

When traffic loads were comparatively light, little trouble, except in isolated cases, was experienced with the failure of the surface to support the load, but as motor trucks have become heavier and heavier numerous cases of road failures are reported from various sections of the country. In some cases these failures are so frequent and so general as to interfere seriously with the serviceability of the road and its entire reconstruction has had to be undertaken after only a few years of service.

Just what do we mean by a subgrade failure of a road

[1] Engineer, Bureau of Public Roads, Washington.

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and what are the conditions that bring it about? Our higher types of road such as are used for motor-truck traffic are not capable of much distortion without cracking or weakening of the road structure. If the strength of the road slab as supported by the underlying subgrade is insufficient to prevent undue distortion under the heavy concentrated wheel loads of trucks, failure of the surface results through the cracking of the slab, and if the subgrade is very soft little time is required for heavy traffic to break up the surface completely and churn it with the underlying mud. Pavements having little or no slab strength will likewise suffer from undue distortion and soon break up under traffic when the subgrade is soft. In many cases, although the incipient failure has produced cracks or serious distortion of the pavement, the final failure may not take place immediately, but the pavement is placed in such a condition as to involve high yearly maintenance expense. If the road surfaces are adequately supported to prevent undue distortion under heavy loads, we should have very few complete and rapid structural failures of roads; they would then fail only after long periods of service through gradual surface wear and disintegration.

The problem of the subgrade is evidently that of finding what causes certain kinds of subgrade material to be soft and of very low bearing value and, having discovered this, to determine what means must be employed to either remedy the condition of the subgrade or fit the design of the road surface to the subgrade. Let us go into the matter a little further and consider something of the mechanics of the problem. Then let us think about some of the various factors involved in producing an unstable condition in the subgrade. First, what happens to the subgrade when it is called upon to support the extremely heavy wheel concentrations of our large trucks? Let us assume that a high type of road having a wearing surface suitable for heavy traffic has been laid on a subgrade of uniform quality and that a heavy truck is at rest on the road surface. Under each wheel there is exceedingly heavy pressure and all of this pressure is necessarily transmitted to the underlying subgrade. The manner in which pressures are transmitted has been given practically no thought and is a subject very little understood by engineers. We have succeeded in gaining some information on this matter with the use of a special cell for measuring soil pressures, which depends in principle upon the balancing of the soil pressure with

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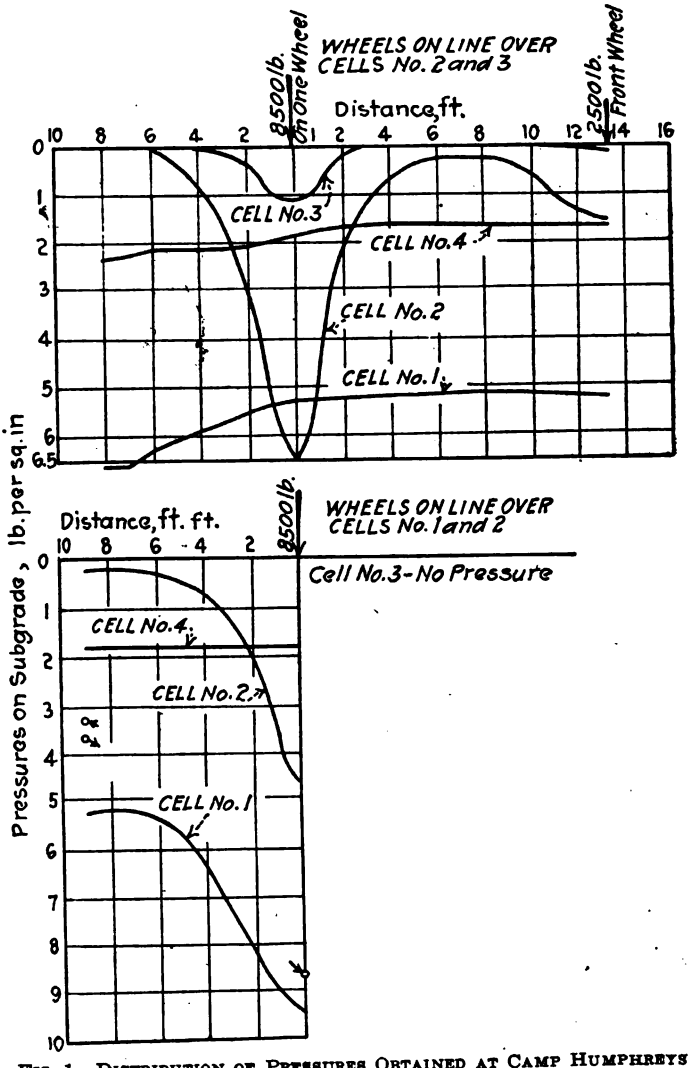

FIG. 1—DISTRIBUTION OF PRESSURES OBTAINED AT CAMP HUMPHREYS WITH A LOADED ARMY TRUCK

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air pressure within the cell and noting the air pressure required for this purpose. This device has been described in a previous paper.[2]

TESTS AT CAMP HUMPHREYS

Some few years ago a test was made on the Camp Humphreys concrete road in which the pressure distribution was determined under each wheel-load. The intensity of pressure on the subgrade is shown in Fig. 1. It will be noticed that the highest intensity of pressure occurs directly under the wheel and that the pressure diminishes according to a curve and disappears about 6 ft. away from the wheel. It will be seen also that in this particular test the maximum intensity of pressure was 6½ lb. per sq. in. A complete description of this test was given in the Bureau of Public Roads publication, *Public Roads*, for April, 1919. The wheel-load producing this pressure was 8500 lb.

Similar tests were made with lighter wheel-loads and it was naturally found that the pressure on the subgrade was less with lighter loads. Very recently a similar test was conducted on the Camp Humphreys road in which a 5-ton truck was used, designed with four instead of two rear wheels, and the curve of pressures on the subgrade as given in Fig. 2 was obtained. This is very interesting because it shows immediately that heavy wheel concentrations produce heavy pressures on the subgrade, but that if the same gross load of the truck is supported on more wheels, thereby decreasing the individual wheel loads, the maximum intensity of pressure on the subgrade is likewise decreased; and, as will be pointed out later, this may mean the success or the failure of the road. Tractor trucks and the use of trailers would be of great advantage from this standpoint at least, since the large gross loads are carried by more wheels. Time will not permit of a detailed discussion of this test; the results are indicated here to point out to truck designers the fact that they can aid in saving our roads and incidentally make available more money for new construction by whole-hearted cooperation with the road engineer and a consideration of the possibility of designing the motor truck with the idea in view of ultimate economy of motor-truck transportation, and with the thought clearly in mind that ultimate economy involves the economy of road

[2] See The Distribution of Pressures through Earth Fills, by A. T. Goldbeck, *Proceedings of the American Society for Testing Materials*, 1917.

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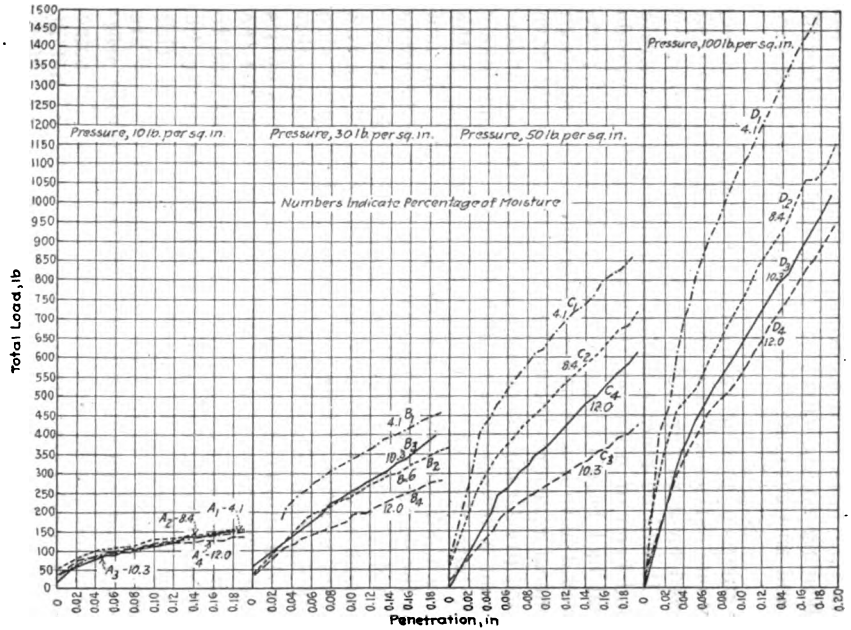

FIG. 2—CHART SHOWING THE BEARING POWER OF SOILS BASED UPON A TEST WITH A 5-TON TRUCK HAVING FOUR REAR WHEELS

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construction and maintenance as well as that of the operation of the motor truck. Other tests we have been making point so clearly to the desirability of close cooperation between the motor-truck designer and the road engineer that I have felt warranted in making a brief digression from my subject. I refer to a large series of tests that have been showing us some surprising results bearing on the effect of the weight and design of truck and tire equipment on the impact on the road surface.

The curves of pressure shown in Fig. 3 apply, of course, to only one particular case, that of an 8-ft. concrete road supported on a rather wet subgrade of poor supporting value. It will be readily understood that if the concrete slab had been of different thickness or if the subgrade material had been harder or softer, the curves of pressure would have had somewhat different values, although the general relations shown by these curves would have remained practically the same. It will likewise be understood that a pavement with slab strength is more likely to distribute the heavy loads over a wider area on the subgrade than pavements having no slab strength, and that at the same time the maximum intensity of pressure under such pavements would be smaller than that under a pavement of the latter type if the thickness of the two pavements were the same. A pavement having no slab strength can be made to distribute heavy wheel concentrations to the subgrade, however, by merely increasing its thickness. We have seen in the tests just cited that the maximum intensity of pressure on the subgrade due to a wheel-load of only 8500 lb. is equal to 6½ lb. per sq. in. This seems like a very small pressure, but even this pressure is very much more than some subgrades are able to support, and this is by no means the highest pressure to which the subgrade may be subjected, for some pavements must carry wheel-loads of 15,000 lb., not at rest but moving and therefore applied with impact.

Soft Subgrades

Suppose the subgrade is so soft that it yields considerably even under so light a pressure as 6½ lb. per sq. in.; under such conditions the pavement is offered very little support by the subgrade and directly under the load a high stress is produced in the pavement if it is distorted thereby to a great extent, and failure is likely to result. It goes without saying, then, that the ideal condition of the subgrade is one in which the greatest possible sup-

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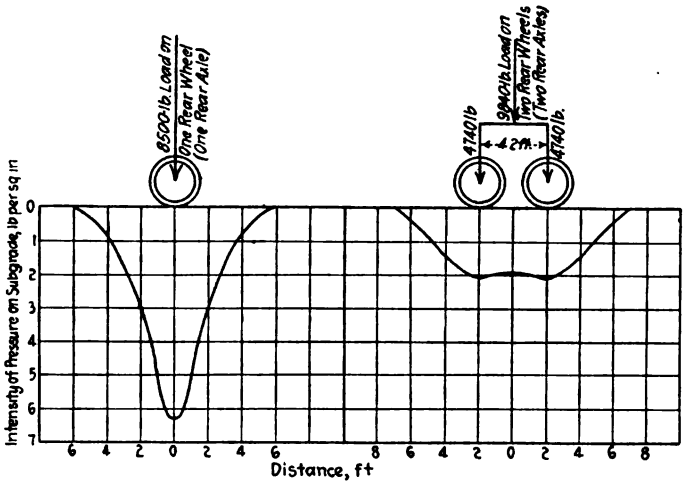

FIG. 3—CURVES SHOWING THE INTENSITY OF PRESSURE TRANSMITTED TO THE SUBGRADE THROUGH AN 8-IN. CONCRETE SLAB

port is offered to the pavement. One does not have to make many field investigations to assure oneself that invariably water is the primary cause of all soft subgrades, but it is not so easy a matter to ascertain to what extent water decreases the bearing value of the wide range of soils encountered. Nor is it easy to specify the best method for getting rid of the water from soils of different types. It has been observed in very many road failures that the subgrade consists of a sticky plastic clay that takes up enormous quantities of water when saturated and becomes very soft in its saturated condition. It has likewise been a matter of general observation that soils of the more porous types, such as sands and gravelly soils, are much more likely to have low bearing value under the continued action of water. Soils are graded between these extremes and no doubt their bearing value varies with the physical characteristics of the soils.

It must not be thought that heavy loads and soft subgrades are alone responsible for our road failures. We have all seen the large shrinkage cracks produced in soils of a clayey nature when they have been baked in the sun. If they will shrink to such an extent as to cause cracking, is it not reasonable that when they are again soaked with water they will show a correspondingly large expansion? And since this expansion takes place in a non-uniform manner, is it not clear that the pavement

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will be given non-uniform support? Moreover, it is important that we do not forget the action of frost. We are all familiar with the volume expansion produced in water as it freezes and when the subgrade is saturated and subjected to frost action, and we know that vertical expansion takes place, which in many cases produces cracking of the pavement by virtue of the inequality of this expansion in different places in the road.

All of us have observed the extreme hardness of many soils when they are perfectly dry, and no laboratory tests are needed to tell us that these same soils when they are made wetter and wetter become softer and softer and finally lose all ability to support loads. It goes without saying that one of our main subgrade problems is that of successfully getting rid of a sufficient quantity of water from the subgrade to render it of high enough bearing value that pressures produced upon it will never be excessive. Our aim should be always to have the bearing value of the soil exceed the maximum pressure produced on the soil by the loads on the pavements. It happens that certain types of soil are extremely difficult to drain, using methods which are successful in other types. It has been found that tile drains that are very successful in some types of soil will do nothing more than reduce the moisture content for a few feet surrounding the drain in other types.

The Drainage Problem

One of the problems before us today is to determine the physical characteristics of soils that are susceptible of drainage treatment of a particular kind. How many engineers would think of using a soil auger in a preliminary survey of the proposed site of a new road? Yet there is no doubt that by taking borings and obtaining samples of the soil at different depths much light will be thrown on the character of support that will be offered by the subgrade and on the possibility of water being retained by the subgrade. It has been observed in several cases where failure of the road has resulted, that 2 or 3 ft. below the subgrade there was an impervious stratum which retained the water in the upper layers and kept it saturated in the spring of the year. Borings will often reveal the presence of a seepage stratum carrying continually flowing water which should be diverted from the road subgrade. These points are cited to show that the subgrade problem involves much field study as well as the mere study of the soils in the laboratory.

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To reduce the water content in the subgrade to a safe minimum, drainage systems will no doubt be needed which in many cases will be very costly. Our subgrade problem is being taken up to lead us to the adequate and economical design of the road. Let us not forget that the road structure involves the subgrade as well as the wearing surface. By strengthening either we strengthen the entire structure. We can, perhaps, cheapen the road surface by strengthening the subgrade, but the strengthening of the subgrade may involve an extraordinary expense and for this reason we must not forget that we may be able in some cases to accomplish our end by strengthening the road surface to the neglect of the subgrade. These are questions of economy to work out when we know more of the methods for treating subgrade materials.

We have spoken of attempting to increase the bearing value of the subgrade by getting rid of the water, but there may be other means for accomplishing the same end. A few years ago a study was made of the manner in which heavy pressures are distributed through fills of different thickness. A typical set of curves showing this distribution is given in Fig. 4. The point to be noticed is that at very shallow depths there is high intensity of pressure and that the deeper the fill the lower becomes the intensity and the wider the area over which the pressure is distributed. This fact is significant, for it shows that if under the wearing surface of a pavement we provide a layer of material having high bearing value, then by virtue of an extra thickness of material the pressure intensity on the underlying soft subgrade may be so much reduced as to keep it below the bearing value of the soil. It is not impossible that some chemical means will be developed for changing the characteristics of soils having low bearing value, although no suitable means have thus far suggested themselves. It is likewise not impossible that by satisfactorily waterproofing the subgrade for a certain depth we can produce a waterproofed layer of material of high bearing value which will serve to distribute pressures to the soft subgrade beneath.

Laboratory Investigations of Subgrades

All of the preceding points are subjects for investigation and at the present time a very definite scheme of investigation of subgrades is being followed out by the Bureau of Public Roads and by other laboratories interested in these problems. Not only have investigations

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including field and laboratory tests been made but special drainage researches are being carried out on a large scale in the field. Some time ago a memorandum was sent to our various Federal district engineers throughout the country asking them to assign men to make special observations on roads that had failed due to soft subgrades and heavy loads. Complete data with regard to these failures were supplied, including a description of the failure, topography of the country, the condition of the drainage system, if any, photographs of the failure, the character of the traffic and in fact all information that could be obtained in the field regarding the cause of the failure. In addition, borings were taken with a soil auger in general to a depth of 5 ft., to determine whether there was any change in character of the soil at different depths, thus furnishing information as to the probable reason for the presence of large amounts of water near the surface. Large samples of the soil were obtained from those spots in the road that had failed and samples of this kind have been shipped to Washington from all over the country. Corresponding observations and samples of material have been taken from sections of some of the same roads that have not failed. We are now subjecting these samples to a number of physical tests and we hope to be able to throw light on some of the questions involved. The samples are being subjected to the following tests:

(1) Percentage of clay and of silt
(2) Mechanical analysis
(3) Slaking value
(4) Cementing value
(5) Compressive strength
(6) Bearing value
(7) Specific gravity
(8) Percentage of water retained by capillarity
(9) Moisture equivalent
(10) Colloidal content, etc.

In the present paper it will obviously be impossible to go into a description of all the methods pursued in these physical investigations, nor will such detail be necessary. These methods are described in a publication which will shortly be issued by the Bureau of Public Roads. It will be well, however, to point out the results obtained on a few samples examined, for these have already shown why roads have failed on certain types of soil and stood up well on other types. The results which

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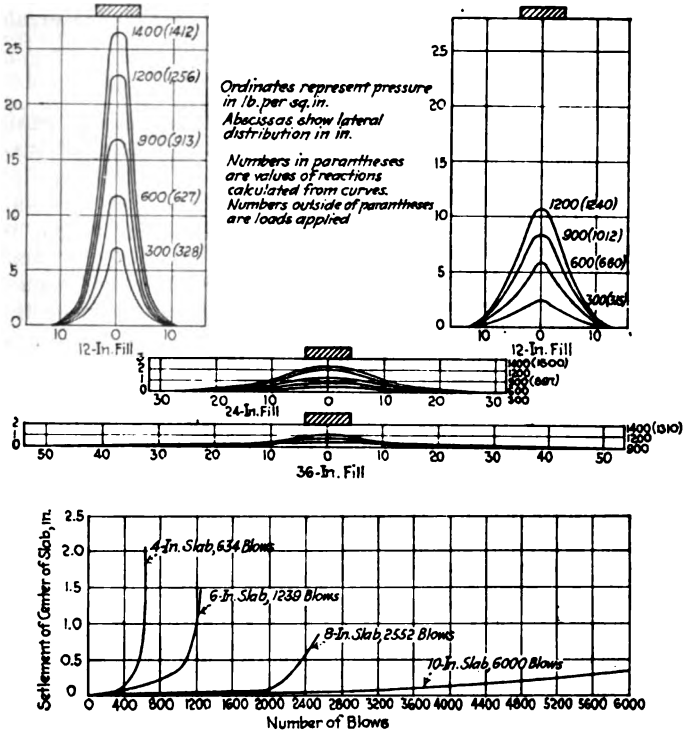

FIG. 4—PRESSURE DISTRIBUTION THROUGH DAMP SAND FILLS

are thus far most significant are the results of the bearing value test. To understand them it will be necessary to describe briefly the methods being followed in making this test. In the natural subgrade of a road soils are subjected to extremely varying conditions. At times they are saturated and again they may be perfectly dry. Sometimes they are expanded through ice action and are thoroughly saturated with moisture in that condition. They may be thoroughly compacted in either a dry or a wet condition. It has been thought necessary to attempt to simulate field conditions in the laboratory, and this is the basis of our present procedure.

The sample of soil is broken up in a mortar by a rubber-covered pestle, care being taken not to break any of the rock fragments. It is then passed through a ¼-in. screen. That portion passing this screen is then run through several rubber rolls to pulverize the soil without

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grinding it. The pulverized soil and the coarser materials are then combined and thoroughly mixed.

Bearing Value Test

The first consideration in making the bearing value test is to determine the range through which the moisture content should be varied. The lowest percentage of moisture is determined by the workability of the soil, that is, just enough water is added to the sample to enable it to be thoroughly mixed and placed in the small mold homogeneously. The maximum percentage should be that which corresponds to the saturation point of the soil. This is determined by the percentage of water the soil will take up by capillarity when loosely compacted. Two intermediate percentages of moisture are taken such that the interval between the four percentages is about the same.

The second consideration is the application of initial-pressure which determines the compaction of the soil. Tentative initial-pressures of 10, 30, 50 and 100 lb. per sq. in. are being used. The complete bearing value test on a sample of soil consists, therefore, of tests with the soil having different percentages of moisture and different applied initial pressures.

Having pulverized the sample, it is mixed with the smallest quantity of water to be used in the series of tests. The sample is kneaded with the hands, protected by rubber gloves, and then placed in a cast-iron cylinder 6 in. in diameter and 6 in. high. The plunger is then placed in the cylinder and the soil compressed in the testing machine under a definite pressure for a period of 5 min. Having subjected the sample to initial compression, the plunger is removed and a circular bearing block placed on top of the specimen; a pressure is again applied at the slowest speed of the testing machine and simultaneous readings are taken of the pressure applied and of the penetration of the plunger. The penetrations are obtained by Ames dials, reading to 0.001 in. Having completed a bearing value test with the smallest initial compression of the sample, the soil is removed from the plunger and replaced and subjected to another initial compression, and the bearing value test is repeated.

When the sample has been tested when prepared with the four initial compressions outlined above, more water is added and thoroughly mixed, and bearing value tests are again run with the soil in the wetter condition. Finally, the test is run with the soil having the highest

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percentage of water mixed with it that a loose sample will take up by capillarity. It will be seen that by performing the test in this way the bearing value is obtained with the soil prepared artificially, much in the same way that it is prepared by nature in that it is subjected to a range of moisture content and a range of compaction.

It is not my wish to enter into a detailed discussion of the results at the present time. I should like, however, to point out certain indications obtained with two soils having considerably different characteristics. It has been stated that observation tells us to expect trouble from road failures in the spring of the year when the subgrade is thoroughly saturated with water. In judging of the bearing value of a soil we should therefore judge it by its saturated condition. The soil shown in Fig. 2 is adobe soil and comes from a road that failed very badly. It should be noticed that this soil absorbed 42 per cent by weight of water when saturated and also that when it was saturated, no matter whether it received an initial compression of 10 lb. per sq. in. as in curves *A*, or 100 lb. per sq. in. as in curves *D*, its bearing value was exceedingly low. In fact, judging from the curves it would seem that in a saturated condition this soil would support a load of barely 2 lb. per sq. in. and under this load there would be continued sinking. A special sand-clay mixture, on the other hand, composed of 75 per cent of coarse sand and 25 per cent of clay, as shown in Fig. 5, absorbed only 16 per cent of water by weight of dry sample when it was saturated, and it will be observed that the curves of bearing value show considerably higher ability to support loads than in the case of the adobe soil. It will be seen also from these curves that soils of this character having a higher percentage of coarsely granular material when densely compacted have a higher bearing value than when loosely compacted even though the soil is saturated. This is unlike the exceedingly finely divided adobe soil. It will be noticed in addition that the sand-clay when saturated has considerably higher bearing value than adobe when both are saturated.

Attention was called to the pressures obtained by actual measurement under an 8500-lb. wheel-load on the Camp Humphreys 8-in. concrete road, the pressure there being 6½ lb. per sq. in. due to this load. The bearing value test on the adobe soil shows it to have a maximum resistance, when saturated, of only 2 lb. per sq. in. Is it necessary to proceed any further to show why certain

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roads laid on certain types of soil have failed utterly? Would we think of designing the footing for a building in such a way as to produce greater pressure on the soil than the supporting value of the soil under that footing? Yet, that very thing is being done in the case of roads laid on certain types of soil, and naturally the soils yield with the distortion of the road surface. Before leaving the curves just described, it is interesting to note the exceedingly high bearing value to be expected even from adobe when it has a low percentage of moisture and it is tightly compacted. Such values are shown by curve *D*. This, of course, bears out our common experience that even the worst kind of clay soil will support heavy loads so long as it is dry and compact.

I do not wish to give the impression that we have proceeded far enough with our investigations to say what physical characteristics soils must possess to render them of high bearing value. I do feel, however, that we are gradually obtaining results which in the end will give us this information. It seems that our results point to the conclusion that finely grained and exceedingly plastic soils, when saturated, are likely to give a considerable amount of trouble and that the coarsely grained, more porous soils which drain well and have a high bearing value will give the least trouble. There is a gradation, however, between these types and it is our aim to couple the bearing value of these gradations with the physical characteristics and likewise with the possibility of these different soils being drained by various systems of drainage.

Drainage Investigations

No soil investigation would be complete without a study of methods for adequately draining the subgrade. It is well known that many roads have failed on fills as well as in cuts when the soil has been of a particular type; also that some soils are not susceptible to drainage such as might be used on other types. We have seen subgrade failures throughout the country where drainage was employed. We have ever before us the constant example of city pavements of comparatively light cross-section very successfully carrying extremely heavy loads, and we are forced to the conclusion that perhaps many of our so-called drainage systems are not as immediately effective as they should be at the time when most needed, in the spring of the year.

Our curiosity has been aroused as to whether some

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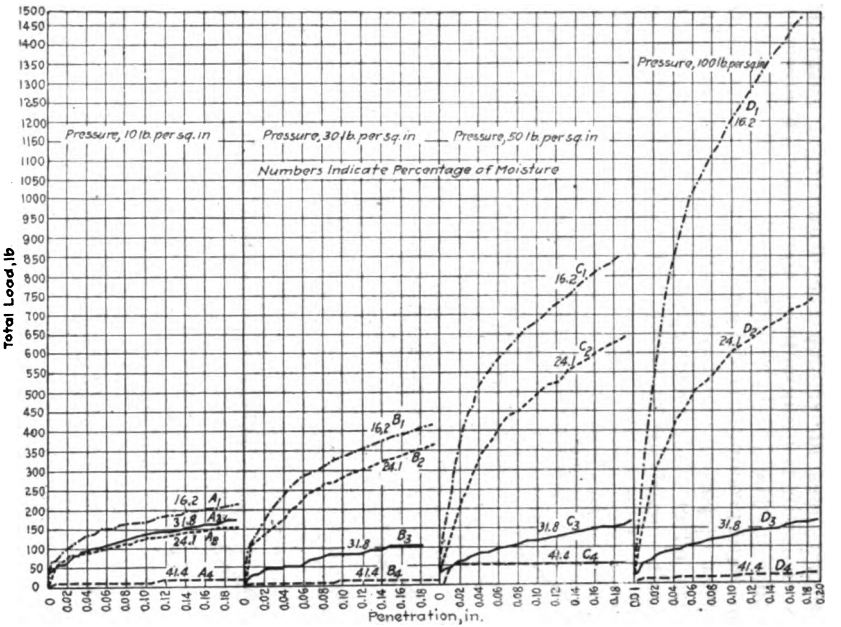

Fig. 5—Chart Showing the Bearing Power of a Soil Composed of 25 Per Cent Clay and 75 Per Cent Sand

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sort of drainage system that will exclude the water from the subgrade should not be designed. Our present drainage systems, it would seem, are built to carry the water away from the subgrade after it has had a chance to make the soil thoroughly wet and soft. In Figs. 6 and 7 will be noted a series of drainage experiments which has been started at Arlington Farm in an effort to determine some principles underlying the drainage of subgrades. This, in itself, is a big subject and cannot be covered in the time allotted. I have mentioned the effect expected from waterproofing the subgrade and the action of the sub-base of porous materials, both of these methods having the effect of decreasing the intensity of pressure on the soft underlying subgrade. Some of the other sec-

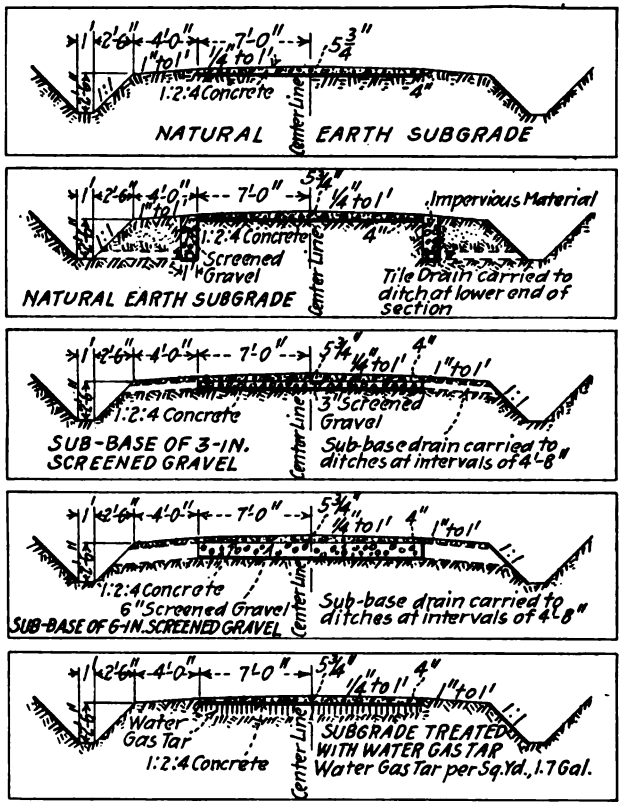

FIG. 6—VARIOUS FORMS OF ROAD CONSTRUCTION WHICH HAVE BEEN TESTED AT THE ARLINGTON FARM OF THE BUREAU OF PUBLIC ROADS TO DETERMINE THE PRINCIPLES UNDERLYING THE DRAINAGE OF SUBGRADES

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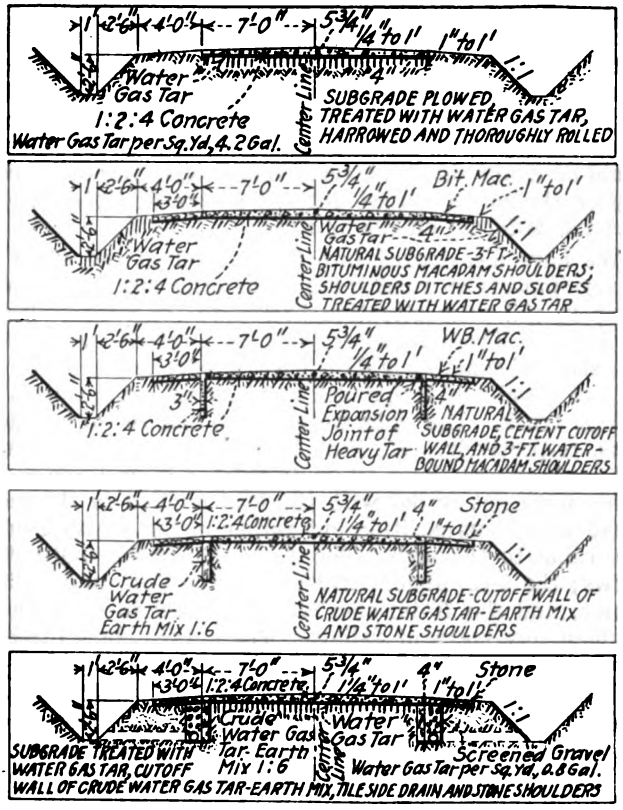

FIG. 7—OTHER FORMS OF ROAD CONSTRUCTION WHICH HAVE ALSO BEEN TESTED BY THE BUREAU OF PUBLIC ROADS

tions, it will be noticed, aim to exclude the water by impervious walls built along the slab. If these experiments prove successful, we hope to carry them out on a large scale with the aid of the State highway departments. Our criterion of success is the percentage of moisture in the subgrades under the various experimental sections. We take samples of the soil under these slabs through openings in the slabs and that section showing the driest subgrade may be considered as most effective. By next spring we shall know if any of the schemes are of value. In conclusion, I want to point out that the amount of research to be performed in connection with highways is almost unlimited. I have spoken of only one phase.

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As some of you probably know, we have been looking into a number of different phases of research, seeking for light on the design of roads to carry heavy trucks adequately. We feel that we have discovered a number of fundamental facts with relation to the impact effects of motor vehicles on roads and if I had the time I could no doubt show you some very interesting data bearing on the subject of weight and design of motor trucks and the different effects of tires.

We have also looked into the subject of the effect of heavy impacts on road surfaces of different types and I wish to call your attention briefly to the curves shown in Fig. 8. These represent results obtained by subjecting slabs of concrete laid on a wet subgrade to impact, an impact exactly like that delivered by the rear wheels of a 5-in. truck. The slabs were 4, 6, 8 and 10 in. in thickness, respectively. We have broken every slab on a wet subgrade except those 10 in. in thickness, and our specimens were not tested with the load applied in the most disadvantageous position but rather in the position most favorable to the slab. The 4-in. slab broke under 634 blows; the 6-in. under 1239 blows; the 8-in. under 2552 blows; and the 10-in. slab was subjected to 6000 blows without any signs of failure. The curves show directly how much difference in strength there is between a 4 and a 10-in slab.

One of our most important problems is to determine whether we cannot obtain satisfactory strength with a comparatively thin slab, provided the subgrade is maintained in satisfactory condition. I mention these experiments in connection with the subgrade experiments merely to give you some idea of some of our problems. The amount of money contemplated for expenditure and actually being expended at the present on road construction is enormous. The day is past for building roads of designs arrived at by rule-of-thumb. Our future designs must be based on sound, scientific, fundamental data. There is too much money involved to have it otherwise. It is our duty to expend this money in such a way that our road structures will give us the most economical service. It is the duty of those having to do with highway transportation, and this involves the truck designer as well as the road engineer, to see that the public supplying the funds get the greatest possible benefit.

Is it not manifest that road engineers and automotive engineers must meet in joint conferences to the end that

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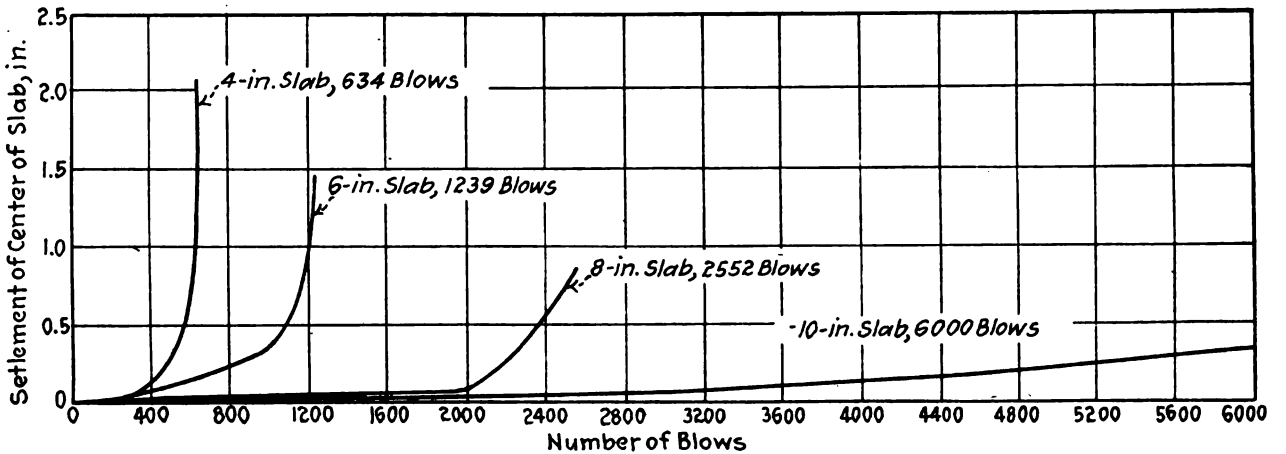

FIG. 8—IMPACT TESTS ON 1 TO 1½ TO 3 CONCRETE SLABS OF DIFFERENT THICKNESSES

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road design and motor-truck design shall be mutually adapted one to the other; and to the end that these designs shall be governed with the goal very clearly in mind, that of ultimate economy in cost of haul? Ultimate economy includes motor-truck economy as well as road economy and many perplexing technical and economic problems will confront such a conference.

[The discussion of this paper is printed on page 123.]

SOME EXPERIMENTS ON THICK WINGS WITH FLAPS

By C D Hanscom[1]

The subject of thick wings has been taking on a constantly increasing importance in aeronautical discussions for several years. Since the war, with the urgent necessity for instant production removed, aeronautical engineers have been turning to practical experiments. The paper presents the results of tests made for the Glenn L. Martin Co. in the wind-tunnel of the Massachusetts Institute of Technology in an endeavor to obtain more data on the action of wings with flaps. Both front and rear flaps were employed. Ultimately four base sections were adopted and the new wings developed from them.

The first, and most logical, choice was the USA-27. The second base section was the H-1, a wing designed by the author, the data for which have not heretofore been published. A third base section was the D-1, designed by G. M. Denkinger. The fourth master section was a composite curve which resembled no wing in particular. From these master curves six new wings were developed, the details and modifications of these being discussed and their characteristics described by curves and tables of data presented together with considerable detailed comment thereon.

The subject of thick wings has been taking on a constantly increasing importance in aeronautical discussions for several years. Since the war, with the urgent necessity for instant production removed, aeronautical engineers have been turning to practical experiments. It should, therefore, aid in general aeronautic development if all information on the subject is made available for common use. The Glenn L. Martin Co. has recently had tests made in the wind-tunnel of the Massachusetts

[1]Jun. S.A.E.—Chief engineer, Glenn L. Martin Co., Cleveland, Ohio.

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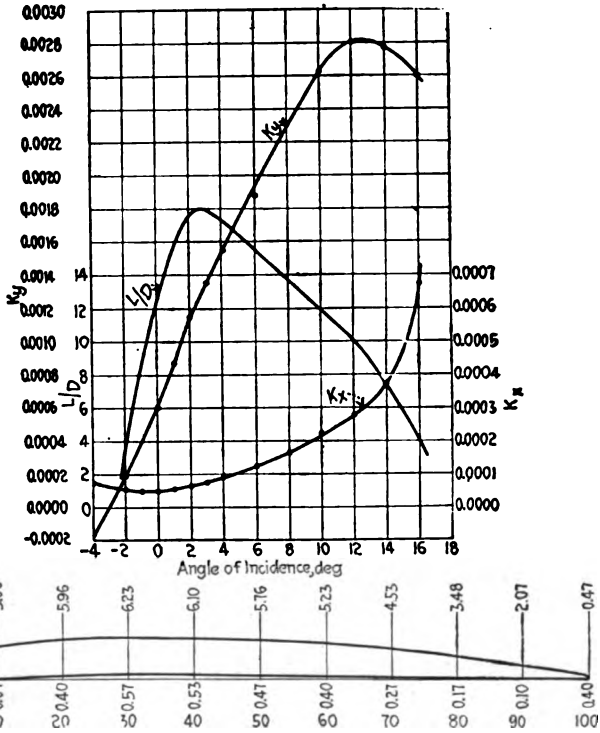

FIG. 1—K_x, K_y AND L/D CHARACTERISTIC CURVES AND SECTION ORDINATES FOR THE D1 WING SECTION

Institute of Technology in the endeavor to obtain more data on the action of wings with flaps. Both front and rear flaps were employed, and the results showed several interesting features. When it was decided to have the experiments made, no sections were at hand which possessed all of the qualifications needed. It was especially desirable that the movement of the flaps should produce minimum discontinuities of surface. This requirement at once limited the choice of sections. Ultimately four base sections were adopted and the new wings developed from them.

FOUR MASTER SECTIONS

The first, and most logical, choice was the USA 27. The wing developed from this section eventually proved the best of those tried. The second base section was a wing of my own, the H1, the data for which have never

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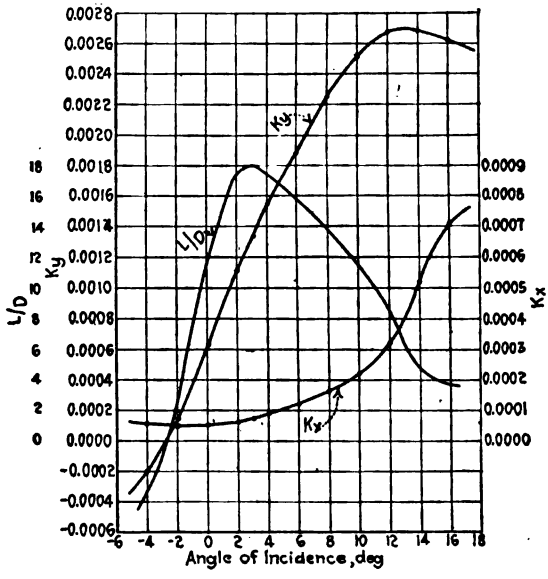

FIG. 2—K_x, K_y AND L/D CHARACTERISTIC CURVES FOR THE H1 WING SECTION BASED ON TESTS MADE AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

heretofore been published. A third base section, which is now being shown for the first time by permission of its designer, G. M. Denkinger, was the D1. The fourth master section was a composite curve which resembled no wing in particular.

From these master curves, six new wings were designed. The USA 27 was thickened appreciably, and minor modifications were made in its form. The new section was called the No. 2. The D1 was uniformly increased in camber, by a percentage ratio, producing the Glenn Martin No. 5. The H1 was modified in three ways. The rear upper surface was raised in all cases to allow more room for the flap. This injured the qualities of the wing to a considerable degree. One wing designated as No. 1 was then made having a sharp trailing edge; another, No. 6, with a blunt trailing edge; and a third, No. 4, with a blunt trailing edge and a practically flat under camber. The fourth master section was modified only slightly, having been designed especially for the purpose. This was called No. 3.

The six models and the sockets were made at the Massachusetts Institute of Technology by its employes.

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The ordinates given in the different illustrations were scaled from sections of these models, and therefore represent to a good degree of accuracy the actual sections tested. The models were all 3 x 18 in., and the wind velocity was always 30 m.p.h. The tests themselves were under the personal direction of Prof. E. P. Warner. I was also present, and at the balance in most cases.

The special qualities which led to the selection of the four master sections deserve attention. The USA 27 was not thick enough, nor did it have a sufficiently high lift for the purpose for which it was needed. It was, however, by far the best thick section known. It was therefore only logical that it should be chosen. The form of the Glenn Martin No. 3 was arbitrarily adopted, the purpose being to combine low drag at small angles with good lift at higher angles. The *L/D* was better than for

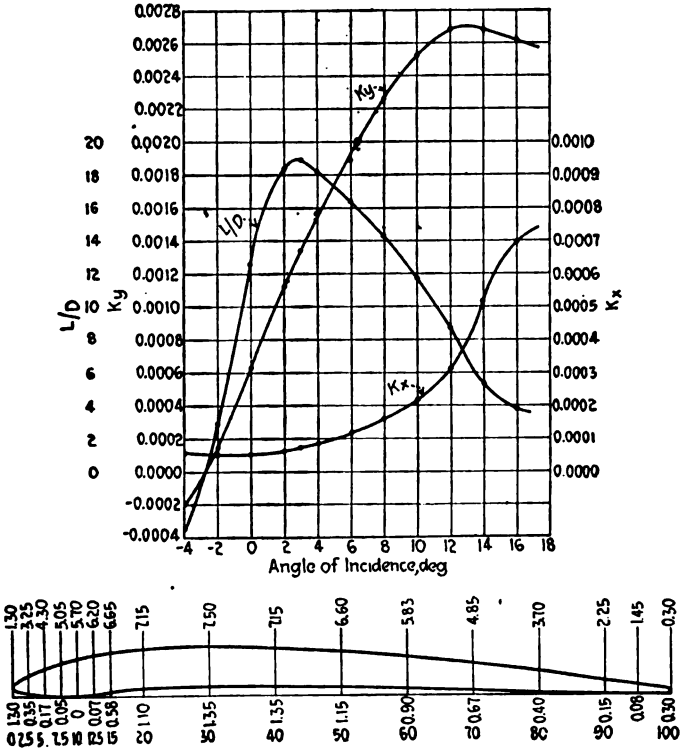

FIG. 3—K_x, K_y AND L/D CHARACTERISTIC CURVES OF FIG. 2 CORRECTED FOR SPINDLE INTERFERENCE AND THE SECTION ORDINATES FOR THE H1 WING SECTION

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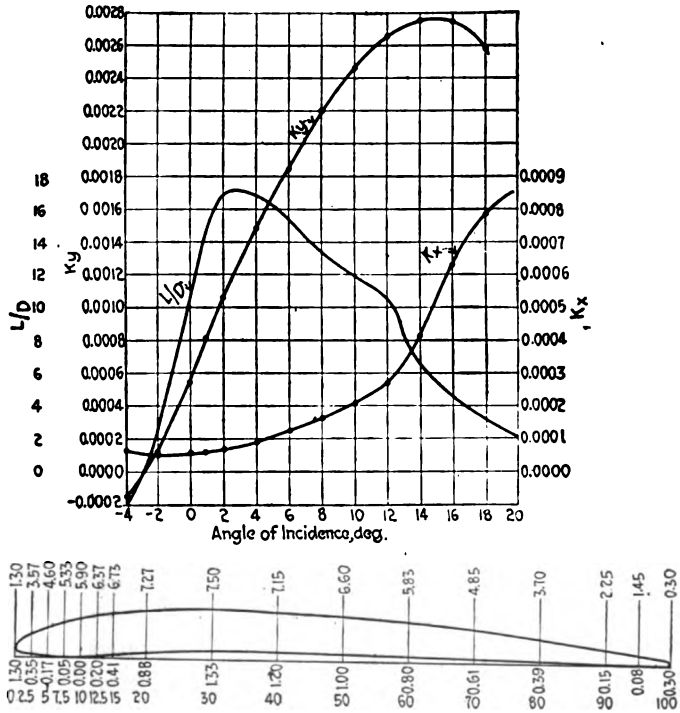

FIG. 4—K_x, K_y AND L/D CHARACTERISTIC CURVES AND SECTION ORDINATES FOR THE H3a WING SECTION

any of the other sections, but the lift proved unsatisfactory. The choice of the D1 and H1 wings was the result of private tests made in 1919. The D1 was designed as a high-speed section. It actually proved to be one of the best known wings, of practical shape, at a lift coefficient of from 40 to 50 per cent of the maximum. In this range, and in fact everywhere above it, the D1 is much superior to the RAF 15. Below 36 per cent, at high speeds, it is inferior, although not greatly so. No change was made in the section in stepping all ordinates up by the same ratio to obtain the Glenn Martin No. 5. The H1 was designed to attain good efficiency at large angles, and if possible, a high lift.[2] The high lift did not

[2] Two sets of characteristic curves are shown for the H1. Those in Fig. 2 having the maximum L/D of 17.9 are the standard Massachusetts Institute of Technology tests. The others, reproduced in Fig. 3, with a maximum L/D of 18.9, show the same data corrected for spindle interference to permit of a direct comparison with the tests performed at the National Physical Laboratory, Teddington, England.

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materialize, but the L/D at climbing speeds varying from 66.6 to 75.0 per cent of the maximum L_c is exceptionally good, being 16 to 15. Two attempts were made to improve the lifting qualities of this section, by thickening the nose, but they failed to accomplish their object. The wings thus produced, H3a and H3b, are practically the same except that H3a has a very slight bump on the lower surface at 50 per cent of the chord. The difference in the characteristic curves shown in Figs. 4 and 5 is, therefore, noteworthy. H3a and H3b, however, merely indicated the advisability of making the modifications in H1 as small as possible.

Unfortunately, H1 had to be changed to a considerable degree to permit flaps to be employed. The rear lower surface had to be bulged down to accommodate the hinges and operating mechanism, and to relieve the sharpness of

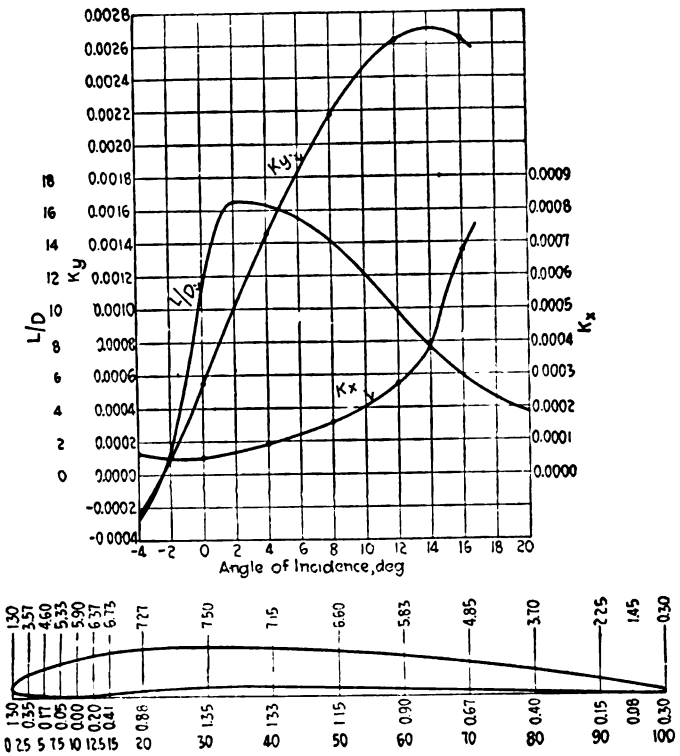

FIG. 5—K_x, K_y AND L/D CHARACTERISTIC CURVES AND SECTION ORDINATES FOR THE H3b WING SECTION

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the break which would occur when the rear flap was pulled down. These changes proved one point in the original design. Efficiency at high angles was obtained in the H1 by making the angles of trail, approximate angles made by the upper and lower rear surfaces to the chord, as nearly the same as possible. In other words, the trailing part was thin. The new Glenn Martin wings based on the H1 apparently lacked any exceptional efficiency at large angles because of the thickening of the trailing part out of proportion to the rest.

New Wing Designs

The six new wings are sufficiently described by the characteristic curves and tables of data. It may be noted

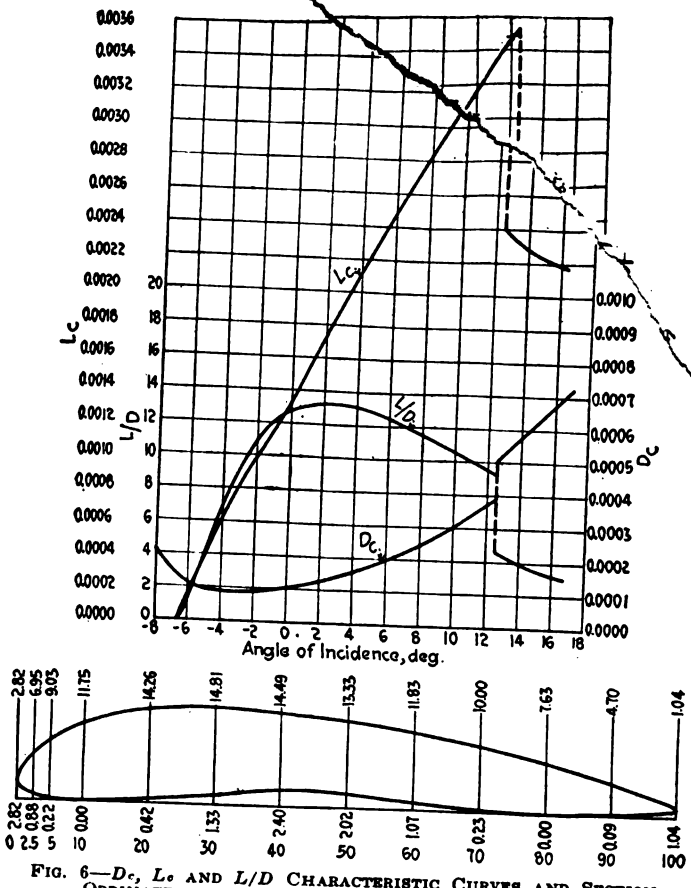

Fig. 6—D_c, L_c and L/D Characteristic Curves and Section Ordinates for the Glenn Martin 1 Wing Section

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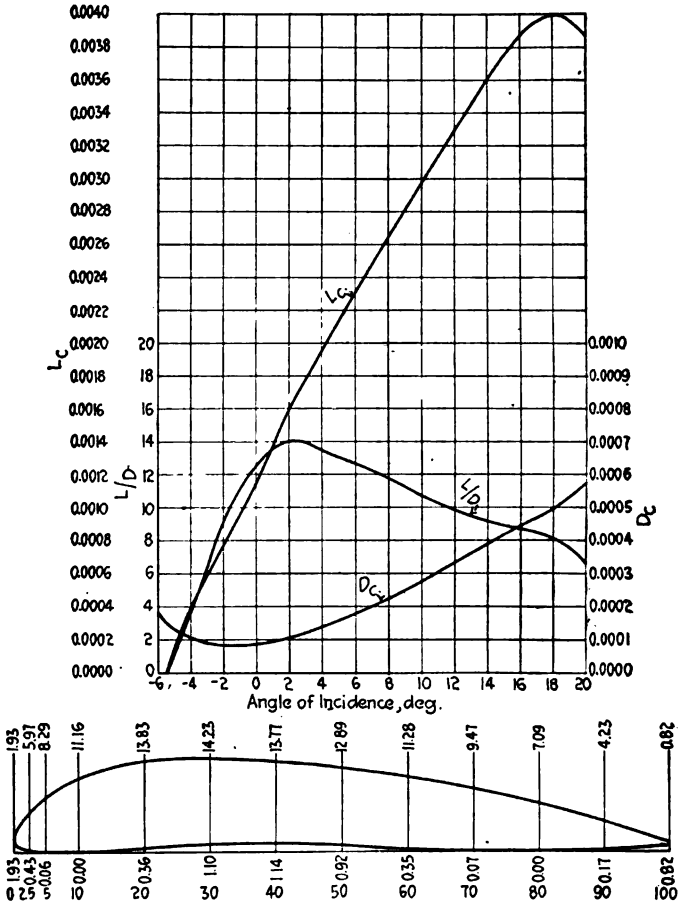

FIG. 7—D_c, L_c AND L/D CHARACTERISTIC CURVES AND SECTION ORDINATES FOR THE GLENN MARTIN 2 WING SECTION

that discontinuities occur in several cases at the burble point. This phenomenon is not unusual for thick wings, and, of course, disappears at higher velocities. It is obvious that the Glenn Martin No. 2 and the Glenn Martin No. 4 are the best of the six. The Glenn Martin No. 5 would undoubtedly have shown a higher lift in proportion as the velocity increased, but its lower efficiency ruled it out.

Sections Nos. 2 and 4 were therefore tested being

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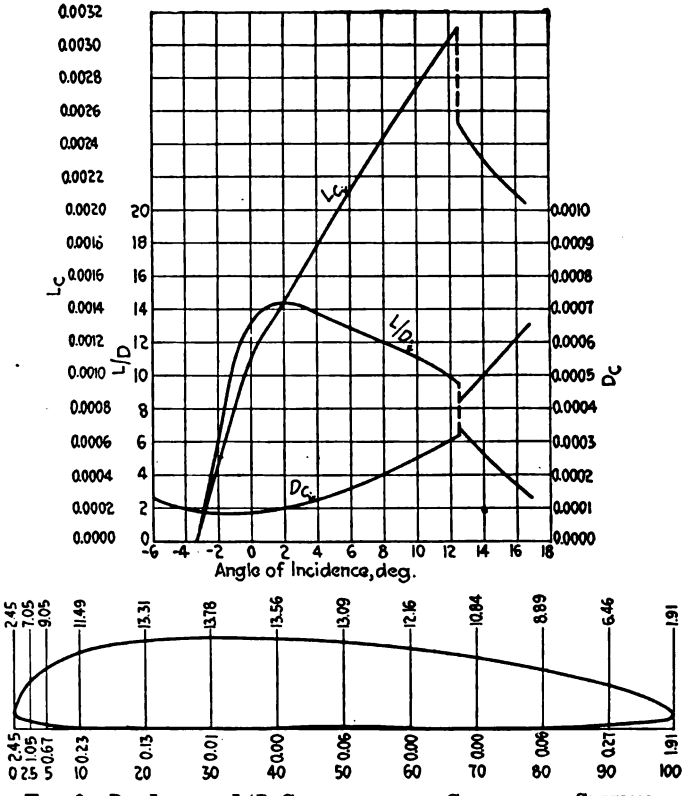

FIG. 8—*De, Le* AND *L/D* CHARACTERISTIC CURVES AND SECTION ORDINATES FOR THE GLENN MARTIN 3 WING SECTION

hinged at 15 and 70 per cent of the chord length. The hinges were approximately 0.03 in. from the bottom surface, and the hinge-plates were sunk flush with the surface. The slight hollows at the hinge-plates and the cracks between the flaps and the main part of the wing were filled with plasticine. The sections were retested, and the errors of alignment noted. It is, of course, impossible to cut a wing in this manner and duplicate the original results, unless the model is metal. The errors, as indicated by a study of the model and the curves obtained, seemed due chiefly to lack of perfect alignment of the flaps. After a standard position for the flaps had been determined, the other tests were run at accurate angles with respect to this standard; but the standard varied slightly from the original wing. Since the en-

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velope curve is the ultimate goal, this minor error, while annoying, is relatively unimportant.

The Glenn Martin No. 4F, which was the No. 4 section with flaps added, was run first. The test demonstrated clearly that at very low angles of lift coefficient a negative angle is best for both front and rear flaps; but that at any speed ordinarily reached, the front flap only should be raised from the normal position. At high values of lift the front flap could profitably be in its

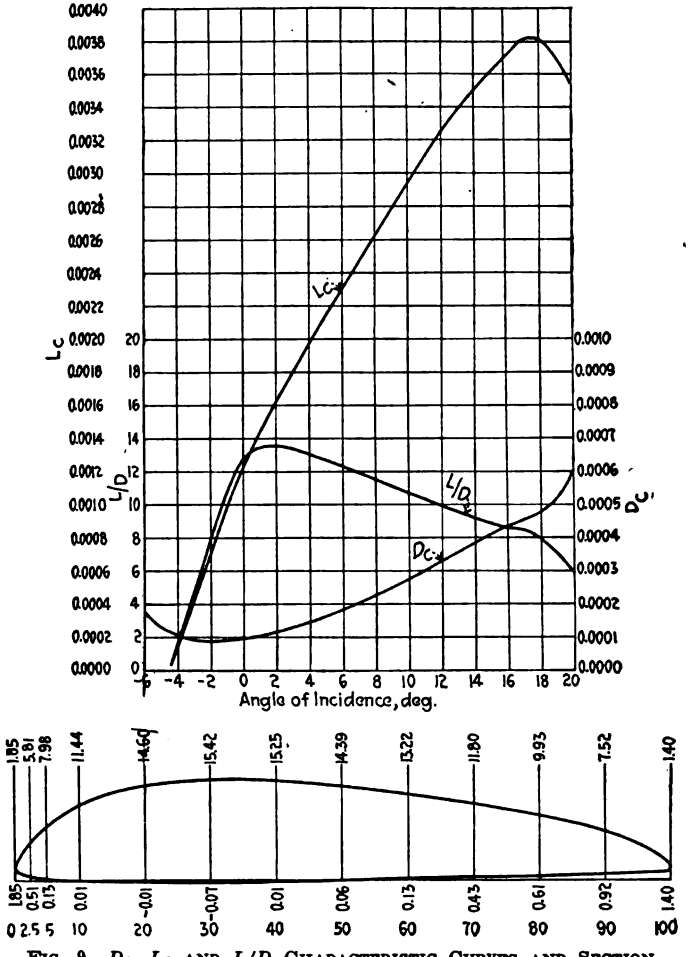

FIG. 9—D_c, L_c AND L/D CHARACTERISTIC CURVES AND SECTION ORDINATES FOR THE GLENN MARTIN 4 WING SECTION

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normal position, and the rear flap should be down about 45 to 50 deg. It is only at the burble point and beyond that there is any noteworthy gain from the lowering of the rear flap.

The Glenn Martin No. 2F gave better results than the No. 4F, as expected. The conclusions drawn in regard to the use of flaps are almost identical. An angle of —5 deg. for the front flap is beneficial at all values of lift up to the burble point of the original wing. At very small

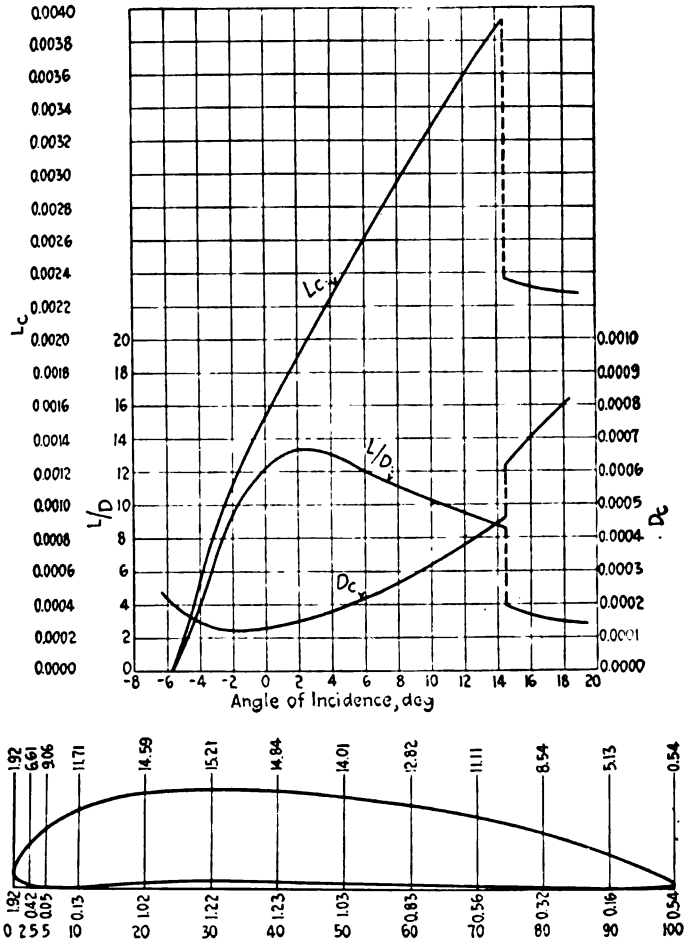

FIG. 10—D_c, L_c AND L/D CHARACTERISTIC CURVES AND SECTION ORDINATES FOR THE GLENN MARTIN 5 WING SECTION

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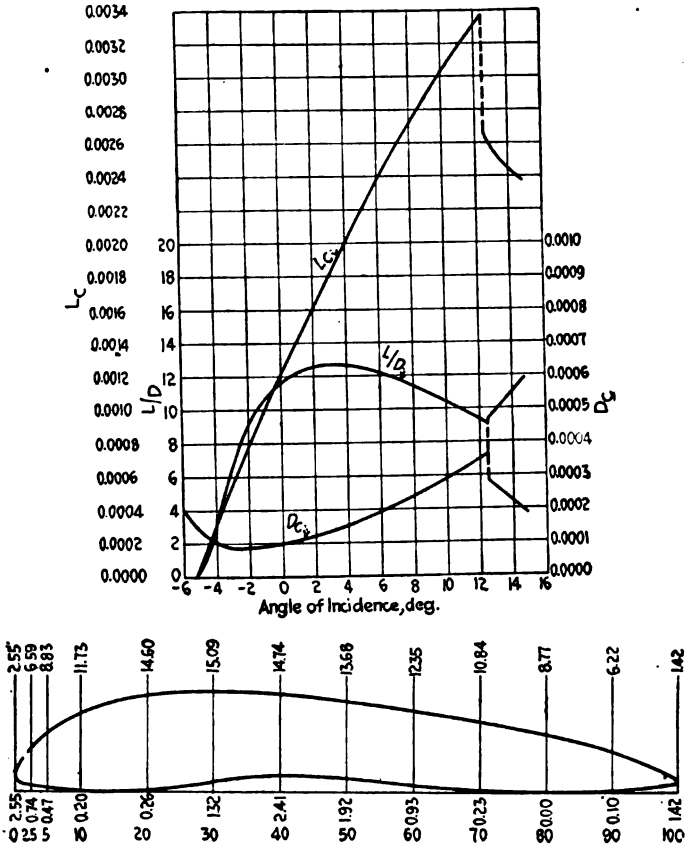

FIG. 11—D_c, L_c AND L/D CHARACTERISTIC CURVES AND SECTION ORDINATES FOR THE GLENN MARTIN 6 WING SECTION

lifts, the front flap can be raised even to —10 deg. with additional gain. In this latter region, also, the rear flap should be lifted to —5 deg. As the burble point is reached, the front flap apparently should come to 0 deg., and from there on the rear flap should be brought down by successive stages to about + 55 deg.

The qualities of the wings with flaps, as indicated by these tests, remain to be considered. The maximum lift increased 25 per cent for the No. 4F and 29 per cent for the No. 2F, over the original wing. These new maxima,[3]

[3]If a correction is applied for the reduction of chord and area with the flaps at large angles, L_c would approach 0.00575 in the case of the No. 2F.

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0.00484 and 0.00516, constitute the highest lift coefficients yet attained as far as I am aware.[4] The drag at this extreme lift is, however, very high. It is interesting to note that for the No. 2F the L/D is 15.1 at 25 per cent of L_c maxima, and 8.4 at 11 per cent.[5] These values of L_c ocrrespond to speeds of two and three times the minimum respectively. It would therefore appear that for racing machines the use of a wing with flaps is highly desirable. For heavy weight-carrying planes, the drag would be high at low speeds; and the performance would resemble that of the Fokker-Junkers, which seems to be slow in pulling up from the ground, but climbs well when a good flying speed is attained.

The effect of an increase in speed and scale is uncertain, since experiments on thick wings with flaps have not been made. There is, however, no reason to believe that the wing characteristics would not improve to an appreciable extent. In any event, full-flight tests can soon settle the question.

THE DISCUSSION

ADRIAN VAN MUFFLING:—Wings have been developed recently in this country that show an L/D ratio of between 26 and 27. It is interesting also to note that the wing-curve is a mathematical curve.

PROF. E. P. WARNER:—For those who are perhaps not able to keep in touch with what has been done on wings, I emphasize the extreme importance and merit of the tests reported by Mr. Hanscom. The 0.00516 lift coefficient obtained is slightly more than 7 per cent higher than any such coefficient that has ever been found before. The highest previous result was obtained in England; this goes far beyond it and it is a much more practical type of wing. Will Mr. Hanscom tell something about the relative merits of the front and rear flaps and whether he thinks the front flap is worthwhile mechanically? Is it not sufficient to use the rear flap alone and leave the front of the wing set in the most efficient position?

C. D. HANSCOM:—Except for very high speeds, very little gain is to be had by changing the position of the

[4]The largest value I have noted elsewhere is that recorded for the RAF 19 in Report and Memorandum No. 648, published by the Advisory Committee for Aeronautics (Great Britain). That report records $C_1 = 0.93$, or $L_c = 0.00474$. The Handley Page apparently only reached $C_1 = 0.8$, or $L_c = 0.00408$.

[5]The corresponding values for the RAF 15 obtained from National Physical Laboratory test are 14.5 and 7.7 per cent.

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leading edge. For a racing machine, or for a machine intended to reach a maximum speed over twice its minimum speed, I think there is value in the front flap; otherwise, not. Professor Warner, having been in charge of the tests that were run, is familiar with these wings.

R. H. UPSON:—Having had considerable experience in airplane trips, especially in those approaching commercial conditions, with the prevailing bumpiness in hot weather, I have wondered whether it would not be feasible to center particular attention on that aspect of the question in the design of the wings themselves; that is, to attempt not only theoretical efficiency but also smooth driving qualities, by the form of the wing, the introduction of spring flaps or something of that nature.

MR. HANSCOM:—I think that would be exceedingly interesting but, aside from the possibilities of the spring flap, I believe much experimenting would be required to determine a wing curve that would give those qualities. I have not gone into that subject and cannot say offhand whether a variation of section would have a very marked effect on the bumpiness.

A MEMBER: — What relative advantages would the leading-edge or trailing-edge flaps have?

MR. HANSCOM:—They operate in different ranges. The change in the position of the leading edge benefits a wing at high speeds. At all L/D ratios the rear flap is the controlling one.

E. R. ARMSTRONG:—From a practical point of view, am I correct in my understanding that you are seeking a high-speed wing that will give low-speed landing?

MR. HANSCOM:—Yes; and also a very high-lift wing, to carry great weight with small size.

MR. ARMSTRONG:—I imagine that is secondary. In a practical machine such as the Martin bombing airplane, where the speed is 120 m.p.h., what would be the minimum landing-speed provided your theoretical deductions were applied to that machine?

MR. HANSCOM:—The testing of these particular wings was finished only yesterday and I have not had time to make examinations as to the properties of the machine. Unquestionably there would be a considerable increase in the maximum speed. These tests have been going on for some time but the last of them have just occurred. Prior to securing the final results we are not doing any development work from the sections.

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MR. ARMSTRONG:—What I had particularly in mind is not the maximum speed but the lowest landing-speed.

MR. HANSCOM:—If we set a minimum speed, we get a higher maximum speed. It works either way. On the present type of machine the difference, I think, would be between 10 and 20 m.p.h.; I cannot say definitely before investigating further. That includes the benefit derived from partial internal bracing. The wings are thick enough to permit considerable internal bracing.

CHAIRMAN GLENN L. MARTIN:—I think Mr. Armstrong desires to know how much lower the landing speed would be, if the airplane were as it is now with the exception of additional flaps.

MR. HANSCOM:—If a newer wing were substituted the landing speed would be cut down from about 60 to between 40 and 45 m.p.h.

CHAIRMAN MARTIN:—In other words there would be a decrease of from 25 to 33 per cent.

CAN AUTOMOBILE BODY WEIGHT BE REDUCED?

BY CHARLES A HEERGEIST[1]

Automobile body building derives its origin from carriage body building, which was highly developed before automobiles were thought of. The introduction of automobile bodies fitted to a metal frame changed body builders' rules and calculations.

The influence of the metal frame is discussed briefly and the limiting sizes of body members are considered also. According to the ideas expressed, the weight of bodies can be reduced if the metal frame is designed so as to support the weight of the passengers and the body. The dead-weight also can be reduced if the frame is built in proportion to the amount of weight carried, the number of passengers and the style of bodies being considered. But in the construction of enclosed bodies, as in sedans, coaches and broughams, very little weight can be saved if stability, durability and lasting quality are to be retained.

There is a demand for economy in the running costs of automobiles. Gasoline costs more than ever before. The heavy car consumes more fuel and wears out tires more rapidly. Custom builders have not been urged by their customers to make cars of light

[1]Technical editor, *Vehicle Monthly*, Philadelphia.

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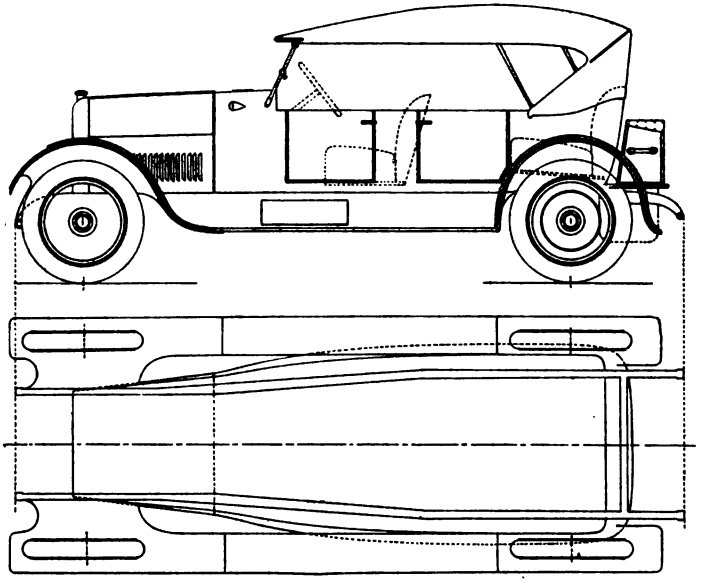

FIG. 1—ELEVATION AND PLAN DRAWINGS OF A FOUR-PASSENGER TOURING CAR BODY HAVING AN EXTREME OVERALL WIDTH OF 54 IN.

weight, possibly because those who can afford custom bodies are not so vitally concerned with the cost of gasoline and tires as the purchasers of lower-priced bodies produced in quantities. Smaller engines can be built, but if the work they have to perform remains the same, these engines must use an equivalent amount of fuel. The work of the automobile engine is proportionate to the weight of the car and passengers, and we cannot decrease the weight of the men and women who ride in our cars. The chassis engineers think the body builders should be doing something toward a reduction of weight.

Nearly all the varied industries which, cooperating with each other, go to form the automobile industry, are comparatively new and of independent origin. One of the few exceptions, perhaps, is the automobile body business, which grew out of the manufacture of carriages, buggies and wagons. Chassis engineers criticize the body engineering fraternity at the present time because they feel they have reached very nearly the limit in lightweight chassis construction, whereas they think the body engineers have made practically no advance in the last 10 years. As a group of body men, we may admit that this is a fairly correct statement of the case. Perhaps

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one of the reasons why so little has been done on the problem of reduction in body weight during the last 10 years is that so many problems of this kind had been solved in the days of the horse-drawn vehicle.

The phaetons, curricles, cabriolets, landaus, broughams and coaches of two decades ago were at the highest development they ever reached in style and construction. The quality of timber and all other material entering into carriage body building, as well as the character of workmanship, was of the very best that could be produced with the materials then available. This has been proved by examining carriage bodies built 50 and 100 years ago, which are still in good condition. Such bodies were built to stand the punishment of bad roads, cobblestones and deep ruts common years ago on country roads.

Buggies and two-passenger phaetons derived their lightness, combined with a remarkable carrying capacity, from the quality of timber and comparatively perfect workmanship entering into them. The landaus were the most troublesome bodies, considered in relation to light weight and carrying capacity, on account of the standing pillars being cut at the fence rails. But this very difficulty gave the body builders exact knowledge as to the dimensions of timber and the sizes of rocker plates required to sustain the weight of the body and the passengers, without any settling of the body on top of the fence rail, between the standing pillars.

It is decidedly necessary that an automobile body should have a solid foundation. Past experience taught body builders a good lesson when the leather-top landaus were in fashion. These bodies had the doors cut at the fence rail, and the rocker plates were sufficiently strong to prevent the doors from closing up at the fence rails, in other words, at the top of the doors. These rocker plates were made ½ x 4½ and ⅝ x 4½ in. when the supports were 101 in. apart, which would correspond to what we call the wheelbase at present.

Application of Carriage Experience

This experience in the construction of open and closed carriage bodies was applied to automobile bodies, which is, in fact, the same as carriage work, and similar rules must be applied to their construction. Automobile bodies are constructed without rocker plates, and the frame has been substituted for them. Consequently, for the foundation of the body we have to depend on the

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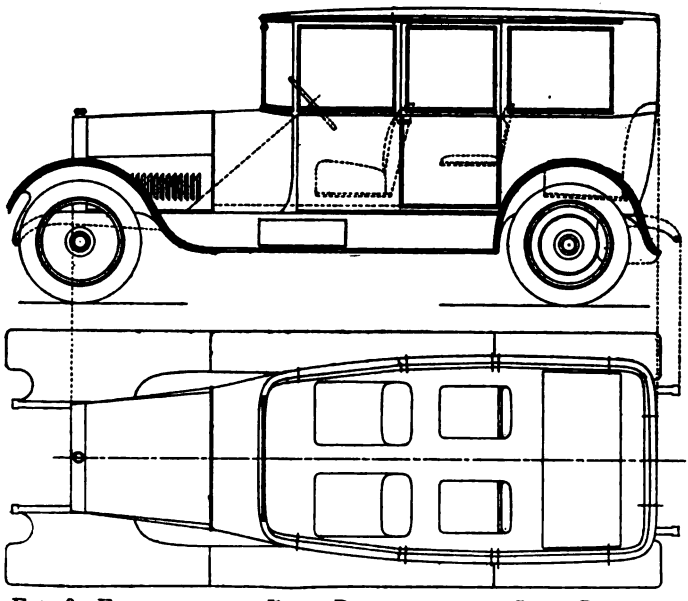

FIG. 2—ELEVATION AND PLAN DRAWINGS OF A SEVEN-PASSENGER SEDAN BODY HAVING A MAXIMUM WIDTH OF 56 IN.

body sills and the frame. Besides this, we must make a distinction between open and closed bodies, in other words, between touring cars and sedans.

The body builder's rule, then, must be not only to keep the body from settling so that the doors can open and shut without any hindrance, but also to keep the body from twisting. As the body builder is in no position to remedy such a condition by himself, he must work in conjunction with the chassis engineer from the beginning to the end, and each should consult the other as to the constructional details of the body and the frame.

If the frame is too weak, it will settle from the weight of the body and the passengers, and from the shocks resulting from uneven roadways. Consequently the frame should be in proportion to the weight it has to carry, with an extra allowance for the shocks caused by the rough roads. No automobile body, even though of the very best material and workmanship, will stand the twisting of a weak frame. It is bound to part at the joints, whether it is an open or a closed body.

Bodies can be built somewhat lighter to obtain a reduction of weight depending on the kind and style of body, but the body engineer can reduce the weight only

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under certain conditions, when these conditions are in his favor. First and most important is the carrying capacity of the frame. All others are only minor conditions.

A hindrance to lighter weight is the use of the same size of frame for a two-passenger runabout as for a six-passenger sedan. The frame is too heavy in the first case; when fitting a six-passenger sedan body on the same frame it may be too light. In other words, frames are frequently out of proportion to the weight of the body and the passengers. If a touring car frame is too weak the door joints at the top of the body will clinch tight, and the doors cannot be opened. This is one of the greatest inconveniences that can happen, especially in the case of accidents. The body engineer in such a case is helpless, no matter how strongly the body is built; the sills and entire body structure will settle if the frame does.

These defects also occur in closed bodies, such as sedans or limousines. If the frame is weak, the front standing pillar or coupe lock pillar on closed bodies will bend toward the door and close up the door joint, preventing the door from operating, besides weakening the body in all its joints. In all cases where the frame is not sufficiently strong the body engineer is helpless because the foundation is too weak to sustain the intended carrying capacity and withstand the road shocks. If the body engineer must build a body on a weak frame, he can avoid most of the trouble by using heavier sills or rocker plates on the inside edges of the sills or filling up the angular frame with stiff timber. This of necessity adds to the body weight.

The practice of using the same kind of frame for a two-passenger and a seven-passenger car is not to be recommended, as, in the case of the two-passenger car, the frame would be too heavy, and for the seven-passenger car it might be too light, and settling between the wheelbase supports might be the result. Reduction in the weight of automobile bodies may be possible, but the stability of the body on the frame must be retained. If the metal frame sags it carries the body with it at every downward movement; consequently the frame should be proportioned to support the weight of the passengers rigidly, and the body built on that frame should be as light as is consistent with stability.

According to the above observations, it is seen that the weight of bodies can be reduced only if the metal

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frame is designed as the real support of the weight of the passengers and the body. The weight can also be reduced if the frame is built in proportion to the amount of weight to be carried, the number of passengers and the style of bodies being considered. In the construction of closed bodies, however, such as sedans, coaches and broughams, very little weight can be saved if stability and lasting quality are to be retained.

An obstacle to lighter weight construction has sometimes been encountered in the widths of frames. French chassis builders have been content with a frame width of 28 in. across the front and 35½ in. across the rear. These frames are suitable for narrow bodies about 50 in. wide, outside measurement, the same as the horse-drawn broughams and coaches were made. This width of 35½ in. was tolerated by body builders, but the narrower the frame the wider the sills had to be made, because the entire length of the sills should rest on the frame to create a solid foundation. Suppose we have a frame 36 in. wide outside, and the width of body is 38 in. outside, with a 3-in. turn-under on each side. The recess caused by the narrow width of the frame when 36 in. wide, will be 11 in. on each side, or 13 in. when the sills have to rest on the frame, making the sills entirely out of proportion, and adding considerably to the weight. On account of the excessive amount of recess, the construction is weakened. American chassis engineers have made an improvement by widening the frame to 40 in. outside, a change which has strengthened the body and reduced its weight. If this width at the rear could be further increased for wide bodies, it would be an advantage to the body designer.

Chassis engineers have also made considerable improvement in the carrying capacity of the frame. In some instances, from the body designers' point of view, they have even gone too far, adding to the weight where it was not needed. A rule should be found to determine the carrying capacity of each frame, but this is difficult on account of the elasticity of the springs, the variability in the load carried, and the occurrence of road shocks. The old-time coach builder found out all he wanted to know by loading the body to its full capacity and then violently jolting it up and down.

Limitations in Weight Reduction.

The body engineer, of necessity, must work under certain limitations in any effort he makes to reduce body

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weight. There are some members of the body framework which must have certain sizes if strong and comfortable seats are to be provided for the passengers. Ample width and height of body are most important. If the width is unduly restricted the passengers will be uncomfortable, and the body must certainly be high enough to afford ample headroom. Both width and height add to the weight. This also applies to what is known as "knee room," which affects the length of the body and adds considerably to the weight. The door and standing pillars must have a certain thickness where the windows move up and down, and a certain thickness to frame the doors and hold the door hinges and locks in their places.

Attention must be paid to the window regulators, which allow the body designer no leeway, since the lift occupies a certain space which cannot be reduced and still provide for the raising and lowering of the glass. Window regulators have supplied us with a convenience that car owners would not wish to dispense with, but they have added weight to the body besides their own.

Concealed door hinges are most desirable and practical, are invisible when the doors are closed and hardly visible when the doors are open. But additional space must be occupied to let them into the pillar, and at the same time the strength of the standing and door pillars must be preserved to prevent them from collapsing. The sizes of such pillars depend on the kind of concealed door hinges used and the pillars cannot be reduced in weight if the required strength is made the same as that of the door and side quarter glass lifts. When plain, straight or curved door hinges are used, the standing pillars can be reduced somewhat, but the amount of weight that can be saved here is so slight that it only counts in connection with other reductions. The weight of door locks has been reduced considerably, but when quality demands that the doors open and shut properly and easily, such locks must have some weight which cannot be reduced very much.

The parts of the body which add most to the weight, are the framework or frame structure of the body and the outside covering. The frame structure has been reduced almost to its limit, considering adequate strength for each part of the body, each part depending on the others to make a strong, solid structure. The sills on a body should not be less than 1½ in. in thickness and the

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width must be such that both sills rest on the frame. The top-rails, cross bars and curves must have a certain size, below which the weight cannot safely be reduced. The outside covering of the body in present practice is either solid wood panels, sheet aluminum, sheet steel, or plywood. Wood panels are only used in connection with aluminum and for custom work. Sheet steel is preferred when a great number of bodies are produced in one model. In the past, plywood has been used chiefly for the tops on closed bodies, but it can be used to advantage where panels of other materials have formerly been used, if it can be shown that weight is saved thereby. For ease of working the metal and its light weight, aluminum has the preference.

I am sufficiently optimistic to believe that ways will be found to build lighter cars and lighter bodies. I have stated some of the limitations under which the body engineer must work, and it is only within such limits that any reductions in body weight can be made.

THE DISCUSSION

GORDON BROWN:—Has any work been done with laminated woods; that is, using thin woods and binding them together with condensation products, such as condensite and bakelite?

CHAIRMAN W. G. WALL:—Do you refer to the cover for the body itself?

MR. BROWN:—Yes, to the wooden panels, to reduce their weight.

A. P. CARDWELL:—So far as I know, no one is building a body from laminated wood panels. The question has, however, been discussed a great deal. I think some panels have been built experimentally.

A MEMBER:—My company has spent about $10,000 in experimental work, largely with fiber wood products. An expert engineer in that particular line was not very successful and I was interested in knowing how the product failed. The hardest part of it was to get fabrication that would be reliable. We specified plywood for roofs. The company which was working on that particular line required a long time to get the manufacturing facilities up to the point where they could fabricate plywood and make it reliable. We found the same trouble in our experiments with plywood for the body. In fact, I think that plywood, so far as quantity production is concerned,

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has not yet been developed in the manufacturing process to the practical point where we can use it in bodies.

MR. BROWN:—In what respect did the product prove unreliable?

A MEMBER:—For one instance, the laminations did not knit together. The particular plywood that we used was supposed to be waterproof; waterproofed glue was used in making the laminations, but it was not waterproof, on actual factory test. Up to the time that we made our specifications, they had been brought up only to the production of comparatively small surfaces. They failed, I think, in trying to make large spreading panels. The experiment which we made with the body, which was very expensive, showed that plywood was not at all suitable. The panels were wavy and a proper surface could not be obtained on them because the fabrication was so imperfect.

LEON OTTINGER:—Regarding plywoods, certain waterproof glues are being made by the Casein Co. of America, which has a laboratory and is glad to help out the automobile trade in regard to any experimenting along the line that was just mentioned. I know that the framework of a body, made of laminated wood and waterproof glue, is being produced now in New York City, and that it has been successful. The body is covered entirely with aluminum, but the framework is all made of plywood and waterproof glue. It is claimed that in the ordinary runabout body about 65 lb. of weight is saved and that the strength is considerably greater than that of any bodies that have been built.

A MEMBER:—Is it a casein glue?

MR. OTTINGER:—Yes.

A MEMBER:—In its experiments our chemical laboratory found that the albumen glue is very much more waterproof than casein. That is what we specified. Our experiments were conducted with albumen glue; that is, blood glue.

CHAIRMAN WALL:—Laminated wood sills are certainly a good possibility.

G. H. WOODFIELD:—I had some experience with the use of haskelite roofs on sedans. This woodwork was supposed to be glued together with albumen glue, or glue made from blood. We put it through some tests. We boiled that wood for 2 or 3 days and could not boil those pieces apart; so, as our laboratory tests showed up very well, we thought we could go ahead and use it with

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safety. We used it on these sedans. The samples we got were fairly good but, when we got into production, it seems that they did something in preparing these panels that removed part of the softer fibers of the wood and made it porous. We could not obtain a surface on them or clean them up so that they would be smooth. Of course that made them objectionable on account of the time required to treat them with filler, rough-stuff them and paint them. We used them, however, but they developed a fine network of cracks all over and we discontinued their use because they were not satisfactory.

A. R. HOPKINS:—We have used a number of laminated roofs and find that our greatest difficulty is in the preparation of the wood paint. We find cracks developing along the joints in the wood. To date, we have no data on the proper preparation of the wood, the preliminary process that the wood must be put through to have it take rough-stuff and the necessary coating to bring about a smooth surface. We have put the roofs through the usual paint operations that we use for a steel surface but, in a number of cases, we found it necessary to scrim the entire roof to get a smooth clear paint jelly. What is the proper process to put these laminated roofs through to secure a smooth surface for the painting?

E. L. BARE:—That trouble has been experienced by several others. We found that medium-grade muslin which covers the entire roof stands up under almost all conditions and is satisfactory in that respect.

E. J. CONNOLLY:—So far as treating the wood is concerned, we have experienced much trouble with plywood for roofs, on account of cracking and not being able to paint it without waves. With this laminated stock for panels and the like, the greatest trouble has been to keep the panels from waving when going through the rubbing-deck operation. The differences in humidity cause the panels to wave more or less. There is no solution, to my knowledge, so far as body panels are concerned, because the same humidity does not exist in the factory while the different operations are being performed.

VICTOR PRESTON:—I think Mr. Heergeist's paper protected the body builders to some extent in regard to why they are not making lighter bodies today. Vehicle bodies have been built for a considerably longer period than automobiles, which accounts for the fact that recent body construction has not shown any marked degree of building lighter bodies, that point having been reached

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prior to the use of bodies in connection with automobiles. I think we must look for an entirely different method of body construction than that in use today if we expect to build a body much lighter and still maintain the strength and endurance required. At the Olympia Show, in London, there was on exhibition a body constructed with a framework of light steel tubing covered with aluminum panels; the manufacturer of it claimed to have reduced the weight to 50 per cent of the usual body construction, while still maintaining the strength.

In reference to plywoods and the like, during the period of making airplane parts for the Government, it was our duty to test thoroughly each batch of plywood received. So far as the practicability of waterproof glue goes, we were satisfied that it would meet the requirements; but one of the reasons that we avoid the use of plywood for body panels is the extra expense in painting them, in both time and material, over that of a metal. Plants producing large quantities of bodies are striving for as low a producing cost as possible, in addition to seeking lightness of body.

A number of car builders depend upon the body to some extent to support the chassis frame, which in my opinion is not practicable. I have wondered as to the possibility of mounting a body on the chassis with a three-point bearing, or in such a manner as to allow the chassis frame to twist without affecting the body.

CHAIRMAN WALL:—There is no doubt that the airplane builder and designer can learn much from the body designer; there are probably a few things that the body designer can learn from the designer of airplanes. The whole basis of body construction, as it is now, depends greatly upon having the chassis frame sufficiently rigid.

F. E. MOSKOVICS:—The building of a body on an automobile chassis is a combination of ancient and modern art to about the last degree. The art of coach-building is some 400 years old; the chassis building art is young. Is it not, after all, a problem of whether we put the structural strength into the body or into the chassis? In 1896 I was working at the Daimler factory in Unter Turkheim, which is now in France. We would build a car and then some one would drive it to Paris. The chassis was designed to carry the calculated load, and it had all the strength and all the rigidity necessary to carry five passengers. We would drive to Paris and go to Kellner, Mühlbacher, Rothschild, or some other body

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builder, who would build on the chassis a body that also was designed structurally to carry five passengers. A man backed by 400 years of precedents in building carriage bodies is slow to accept instruction. We would give him instructions not to interfere with the spring action, the steering-wheel and the gearshift and the brake levers; then he would build the body with no mechanical cooperation between the chassis and the body engineer.

Someone suggested that if this body were built out 4 or 5 in. the passengers could be put in at the side instead of at the rear. As I see it, that was the only point of contact between the coach builder and the chassis builder up to about 4 or 5 years ago, and it is the only real structural development I have seen in body design before the advent of the very deep thin-section frames, in the case of which practically all the strains of the actual road shocks and twists are carried by the frame.

The body of one well-known car is made in three sections without any sill. The actual floor-board height above the frame is less than ¾ in. Each of the sections is bolted on the frame separately. In addition to being bolted to the frame, the rear section has an angle-iron which is bolted again with the idea of having it carry the top strains. The body is made entirely of aluminum, the only purpose of the wood used being to provide fastening bases for the aluminum panels and the upholstery. It is a very light construction and the job is very easily handled in a shop.

L. C. HILL:—Before attacking any problem of weight reduction in passenger-car bodies, it is necessary to make a careful analysis of the detail weights which constitute the total weight of a particular type. These can be grouped into three classes

(1) Parts essential to the structure, whose weight cannot be reduced materially
(2) Parts whose weight might be decreased, but at a considerable expense
(3) Parts which may be of lighter design, made of lighter material, or discarded entirely

It is the last class which deserves the study of the designer and, unfortunately, it appears to be the one holding the least promise. It must be understood that I am referring to only the particular type of body structure now in universal use. Radical designs must be resorted to if much decrease in weight is expected in the first two

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classes. There are details such as windshields, window glass, floor-boards and upholstery in these classes. They constitute a group which is essential and yet it is difficult to reduce their weight.

The use of airplane materials and practices in body construction has been a disappointment to many body men who were engaged in the airplane field during the war. There is a definite reason for this failure. The airplane is never expected to stand the abuse given the average car body and still maintain a high finish. It is carefully groomed by an able corps of mechanics and properly maintained at all times. Contrast this with the neglect accorded the average automobile; and yet the owner demands excellent finish and sturdy construction.

VOLATILITY OF INTERNAL-COMBUSTION ENGINE GASOLINE

By Frank A Howard[1]

After stating that the meaning of the term "gasoline" seems to be generally misunderstood for the reason that it has been assumed that gasoline is, or ought to be, the name of a specific product, the author states that it is not and never has been a specific product and that although gasoline has a definite and generic meaning in the oil trade it has no specific meaning whatever. It means merely a light distillate from crude petroleum. Its degree of lightness, from what petroleum it is distilled and how it is distilled or refined are unspecified.

Specifically, "gasoline" is the particular grade of gasoline which at a given moment is distributed in bulk at retail. It can be defined with reasonable precision as being the cheapest petroleum product acceptable for universal use as a fuel in the prevailing type of internal-combustion engine. The author places emphasis on the three factors of this definition: (*a*) the cheapest product, (*b*) its universal use and (*c*) the prevailing type of internal-combustion engine.

The author's purpose in this paper is to clear away some of the haze which surrounds the word "gasoline" and with regard to what volatility is with reference to engine gasoline to show how much of the difficulty is inherent in the fuel and how much of it arises from the failure of automotive engineers, collectively, to attain a

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high average of perfection in the handling of the fuel to develop power.

Ordinary engine gasoline of the grade now sold possesses sufficient inherent volatility to take and maintain the condition of a gas at a temperature at or below average intake-manifold temperatures. Manifold condensation seldom, if ever, occurs and cylinder condensation is even less probable. The phenomena answering to these names are in fact mainly the visual evidences of the failure of the vaporizing device to function. Fuel once vaporized must stay in that condition; hence, if liquid is found beyond the vaporizer, it reached there as a liquid.

These conclusions are based on an examination of the fuel itself. The volumetric proportions of a combustible mixture are considered in detail in the paper and the physical meaning and measurement of volatility are fully discussed, tables of vapor-tensions being given and the special apparatus developed to determine the vapor-tension of gasoline being exhibited and described. Following this a full discussion of the requirements for full utilization of inherent volatility is presented, the conclusion reached being that the problem resolves itself into the further development, improvement and wider use of the hot-spot.

The meaning of the term "gasoline" seems to be generally misunderstood for the reason that it is assumed that gasoline is, or ought to be, the name of a specific product. It is not and never has been a specific product; whether it can be, or should be, I shall leave to your judgment.

Gasoline has a definite and fixed generic meaning in the oil trade, but no specific meaning whatever. It means merely a light distillate from crude petroleum. Its degree of lightness, from what petroleum it is distilled and how it is distilled or refined are unspecified. It may not be known generally that practically every grade of distillate which was ever popularly known as gasoline is still made and sold. It is not sold as gasoline, but is distributed under its specific trade or technical name, such as "76 naphtha," "66 naphtha," "P C naphtha," or something else. Such sales are only at wholesale or on a contract basis as a rule, not through the retail bulk-distribution systems for engine fuel. No product of the nature of gasoline can be economically distributed at retail in bulk unless there is a large and constant demand. This is our clue to the only specific meaning of the word gasoline. Specifically, "gasoline" is the particular grade

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of gasoline which at a given moment is distributed in bulk at retail. I think it can be defined with reasonable precision as being the cheapest petroleum product acceptable for universal use as a fuel in the prevailing type of internal-combustion engine. I emphasize the three factors of this definition: (*a*) the cheapest product, (*b*) its universal use and (*c*) the prevailing type of internal-combustion engine.

So long as there is any such thing as a single prevailing type of engine and so long as there is substantial unanimity of view as to the acceptability of any single grade of product in this engine, the definition I have given is practically an axiom. This has been the condition up to the present time, and it is in some ways an ideal one. On this point, however, I am holding no brief. My sole purpose in this discussion is to clear away, if possible, some of the haze which surrounds the word "gasoline." If I have helped to make clear the fact that gasoline in the specific sense in which it is used does not purport to be a fixed product, but only the official title of the successful bidder for popular patronage in the engine-fuel market, my purpose will have been served. Until we have a Volstead act on engine fuels, prohibiting the manufacture and sale of any hydrocarbon product containing more than ½ of 1 per cent boiling above 300 deg. fahr., unless denatured with a sufficient quantity of carbon tetrachlorid or other approved fire extinguisher to make it poisonous to any misguided engine which may attempt to use it internally, I do not see how we are to prevent some enterprising refiner from offering to the public an engine fuel different from that which has been previously sold as gasoline. If it gives more service at lower cost than the competitive products, I do not see how we are to keep the public from buying it or prevent the public from continuing to call it "gasoline" if so minded.

I shall try to tell what volatility is with reference to engine gasoline. The prevailing type of engine up to this time has been essentially a gas engine, an engine which consumed its fuel in the form of a gas. The two prime requisites of the gasoline are, therefore, that it be a fuel, and that it be capable of conversion into a gas. So far as I know, no one has yet questioned the fact that gasoline is a fuel, but there seems to be a widespread conviction that it cannot be gotten into the cylinders in the form of a gas. This low volatility of gasoline, and its volatility is low, is the root of most of the trouble which

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is being and will be met with. My purpose is to show how much of the difficulty is inherent in the fuel and how much of it arises from the failure of automotive engineers, collectively, to attain a high average of perfection in the handling of the fuel. This is not a criticism. Among engineers, at least, I think it safe to refer to an engine as 10-per cent or 50-per cent efficient, without the deduction being drawn that the responsible persons are being haled before the bar of public opinion for their 90 per cent or 50 per cent of shortcomings.

Ordinary engine gasoline of the grade now sold possesses sufficient inherent volatility to take and maintain the condition of a gas at a temperature at or below average intake-manifold temperatures. Manifold condensation seldom, if ever, occurs and cylinder condensation is even less probable. The phenomena answering to these names are in fact mainly the visual evidences of the failure of the vaporizing device to function. Fuel once vaporized must stay in that condition; hence, if liquid is found beyond the vaporizer, it reached there as a liquid. These conclusions are based on an examination of the fuel itself. Here is the evidence; first chemical, then physical.

Volumetric Proportions of a Combustible Mixture

As a corollary of Avogadro's law, the volumetric proportions of a mixture of gases are represented by their molecular proportions, and these in turn are represented directly, in the case of a gaseous fuel mixed with the proper amount of air for combustion, by the equation of combustion itself. For example:

$$C_5H_{12} + (8O_2 + 32N_2) = 5CO_2 + 6H_2O + 32N_2$$

From the equation it therefore appears that a perfect mixture of pentane gas, or vapor and air, must consist of 40 parts by volume of air made up of 8 parts of oxygen and 32 parts of nitrogen and 1 part by volume of pentane. Pentane is the lightest hydrocarbon found in any substantial amount in gasoline. Again:

$$C_{11}H_{24} + (17O_2 + 68N_2) = 11CO_2 + 12H_2O + 68N_2$$

This shows that a perfect mixture of vaporized undecane and air comprises 1 part of the fuel and 85 parts of air, by volume. Undecane is probably the heaviest hydrocarbon present in any substantial amount in gasoline.

Since gasoline consists of hydrocarbons lying between these limits, there being more of the lighter than of the

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heavier, the volumetric proportion of gasoline vapors in a perfect mixture will be somewhere in the neighborhood of 1 part in 60, or 1.67 per cent. It may help us to appreciate this if I say that the air of this room normally contains a proportion of water vapor just about this high. If water were gasoline, we would be living in a substantially perfect combustible mixture most of our lives. If we can visualize this condition, it will be easier to follow the physics of this question.

The boiling point of water at sea level, under a normal barometer, is 212 deg. fahr. Nevertheless, the air of this room contains something between 1 and 3 per cent of water vapor. How did it get here and why does it stay here? It got here by evaporation from the sea and it stays here because it cannot condense. Apparently, therefore, the boiling point of water, or of engine fuel, does not fix the temperature at which it evaporates and stays evaporated. Some other factor must be involved. This factor is the *proportion* of vapor in the air. The boiling point is the temperature at which there is 100 per cent vapor in the air, which is an Irish method of stating the fact. Since automotive engineers are interested in a perfect mixture containing less than 2 per cent of vapors of gasoline, it would appear, therefore, that the boiling point of the gasoline is more a matter of academic interest than a critical measure of its volatility. From an automotive engineering standpoint, the volatility of the gasoline is to be determined by its ability, or lack of ability, to form a stable 1 or 2-per cent mixture with air, and not by its ability to form a 100-per cent cloud of gas pushing the air away ahead of it, which is the phenomenon called boiling. If it is a light gasoline, such as pentane, we want it to be stable up to about 2 per cent; if it is heavy, like undecane, we want it to be stable up to about 1 per cent. From this we draw the interesting conclusion that the lighter the fuel is, the greater its volatility must be to permit it to exist as a stable mixture. Roughly, pentane must have twice the absolute volatility of undecane to be equally volatile from a carburetion standpoint. It actually has more than twice the absolute volatility, but the thing to be borne in mind is that a comparison of absolute volatilities will be very misleading unless read with a combustion equation which fixes the required volatility. The true comparison is the relation of absolute to required volatility of the fuels compared.

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Physical Meaning and Measurement of Volatility

The physical laws which govern the volatilization or vaporization of liquids were clearly enunciated by Dalton about a century ago. These laws, or the one law and its corollaries, are generally referred to as Dalton's Laws of Vapor-Tension, and can be stated adequately for the purpose of this discussion as follows:

(1) A liquid will continue to evaporate from an exposed surface thereof until there is established on that surface a definite pressure of the vapors of the liquid

(2) This definite pressure changes with the temperature of the liquid, but is independent of the presence, character or quantity of any other gases or vapors existing above the liquid

(3) This definite pressure is called the "vapor-tension" or "vapor-pressure" of the liquid at that temperature. If the vapors of the liquid are admixed with other vapors or gases, the total pressure of the mixture multiplied by the volumetric percentage of any constituent gives what is plainly named the "partial pressure" of that constituent. So long as this partial pressure of the vapor in question is below the vapor-pressure of the liquid at that temperature, condensation cannot occur

The usual method of measuring the volatility or vapor-tension of a liquid is to introduce a sealed vial of the liquid into the space above a mercuric barometer column, then to break the vial and read directly the lowering of the barometer which shows the pressure developed by the vapors of the liquid. This, of course, gives the vapor-pressure in vacuo, which, according to Dalton's laws, should be the same as that developed in air or in any other gas. Generally this is true, but in the case of gasoline and some other mixed liquids the results obtained differ slightly from measurements made in air. Since we are directly interested in the vapor-tension in an atmosphere of air, the form of instrument designed by C. I. Robinson, chief chemist of the Standard Oil Co. of New Jersey, is preferred. This instrument is illustrated in Fig. 1. It consists of a graduated U-tube *a*, one leg of which is surmounted by an air bulb *b* cut-off by cocks. The upper one is a two-way cock and this, in turn, is surmounted by a feed reservoir and trap *c*. In using this instrument, both legs of the tube, as well as the reservoir and the trap, are filled with liquid to be measured, leaving the cut-off bulb filled with air. The two

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legs of the tube are balanced. Liquid is then permitted to drop through the bulb for a few minutes. The upper cock is closed, the legs are balanced again and the increase in the volume of air is read directly on the graduated leg of the tube. The temperature is controlled by immersing the whole instrument in a water bath before and during the measuring.

With this instrument, the absolute volatility of an average 58-deg. Baumé engine gasoline of the present-day grade was determined as follows: first the vapor-tension of the original gasoline was determined at two temperatures. Then the sample was reduced by distillation in the ordinary way, taking off successive 10 per cent fractions. After each reduction operation the vapor-tension of the residual portion of the gasoline was determined at temperatures of 50, 75, 100 and 125 deg. fahr. Table 1 gives a complete inspection of the original gasoline and Table 2 shows the results of these measurements.

In dealing with a complex liquid such as gasoline, the full interpretation of these results carries us much

TABLE 1—57.9-DEG. BAUMÉ ENGINE GASOLINE USED FOR VAPOR-TENSIONS

Temperature, deg. fahr.	Percentage Off
Start 108	..
122	2
140	4
158	8
176	12
194	17
212	23
221	26
230	29
248	36
266	43
275	47
284	51
302	60
320	68
338	75
356	83
374	88
392	92
410	94
428	96
Final 435	97 Recovered

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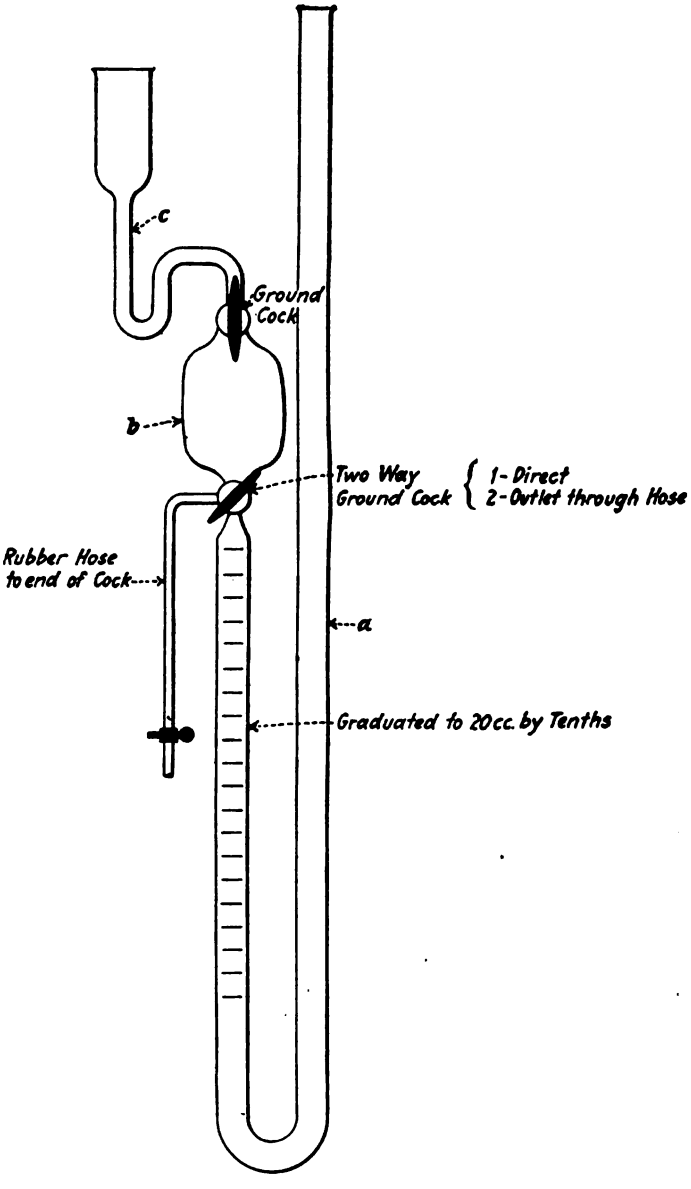

FIG. 1—SPECIAL APPARATUS DEVELOPED TO DETERMINE THE VAPOR-TENSION OF GASOLINE

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further into the field of the physical chemist than it is necessary for us to go today. We are dealing specifically with the question of minimum volatility. Is gasoline inherently volatile enough to permit complete vaporization at ordinary manifold temperatures or is it not? Let us, therefore, take the heaviest portion of the gasoline, the last 10 per cent, which we find has a boiling-point range of 380 to 435 deg. fahr. It is this portion which some of you automotive engineers have urged the refiners to cut-out, stating that it cannot possibly be vaporized or kept from condensing and is, therefore, not only of no value but actually detrimental to the engine. Returning to our combustion formula we find that if the fuel were composed entirely of this very heaviest fraction, a perfect mixture would contain about 1.2 per cent of fuel vapor. The average pressure in an engine manifold is around 0.5 atmosphere. Calling it 400 mm. of mercury, 0.012 x 400 = 4.8 mm.; which is, therefore, the partial pressure of fuel vapors, assuming that we have a fuel made up entirely of the least volatile fraction of the present gasoline. We find that at any temperature above 125 deg. fahr. the least volatile portion of the gasoline has a vapor-pressure well above 4.8 mm. Our conclusion must be, therefore, that even if the gasoline consisted entirely of what is at present its heaviest constituent, it would still possess sufficient inherent volatility to make it a possible fuel for an engine essentially a gas engine. It is a fuel and can become and must remain a gas at an intake temperature not substantially higher than present practice.

This examination of the volatility of a typical engine gasoline does not represent the whole of the problem by any means, but it does indicate what is possible and what is impossible. Stating it generally, complete vaporization of fuels much less volatile than those now sold is possible without increase of mixture temperatures; condensation of these fuels is impossible. Let us first dispose of the last statement. Manifold condensation is impossible, above the temperature indicated, because it is physically impossible for any vapor to condense when its partial pressure is lower than the determined vapor-pressure of the liquid itself at that temperature. This is apparently the average condition in an engine manifold. So far as I know, there is no malicious mechanical magnetism in a gas engine which suspends the operation of the laws of nature. So-called "condensation," in most cases at

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TABLE 2—VAPOR-TENSIONS IN MM. OF MERCURY AT VARIOUS TEMPERATURES

Temperature, deg. fahr	50	75	100	125	Specific Gravity, Bottoms
Original Gasoline	121.80	180.05	.....	.....	.....
Residuum, per cent					
90	44.75	69.51	115.20	156.35	54.6
80	17.45	31.18	54.92	103.20	52.9
70	16.65	24.65	41.49	69.75	51.3
60	9.66	14.35	24.59	45.82	49.8
50	8.45	13.35	18.41	29.50	48.4
40	4.84	8.08	11.32	17.50	46.2
30	....	6.75	8.48	12.55	45.3
20	....	....	1.64	8.05	43.1
10	....	....	....	5.07	40.1

least, must therefore be the mere separation of liquid which was never vaporized. Precisely there lies the difficulty. Vaporization is possible, and without higher manifold temperatures; but it is difficult to obtain.

REQUIREMENTS FOR FULL UTILIZATION OF INHERENT VOLATILITY

The utilization of the full inherent volatility of the fuel is dependent upon just three things, time, surface and heat. The relation can be expressed mathematically as follows:

$$\text{Vaporization} = \text{Time} \times \text{Surface} \times \text{Heat}.$$

If the time element is large, surface and heat may be infinitely low. If surface is infinitely large, the other two may be infinitely small. If heat is applied rapidly enough and at a high enough potential or temperature, surface and time become unimportant.

So far as I know, no way is promised yet for bettering the time factor. The other two, however, automotive engineers are bettering daily in several ways. Air heating and manifold heating are helpful, but apparently the means which best meets the physical requirements of volatilization is the so-called hot-spot. The definite problem is to supply heat to the fuel; not to supply heat to the air or to the mixture, but to the fuel itself. This heat should be supplied to the fuel in the presence of the air to have its maximum effect. The latent heat of evaporation of gasoline is about 130 B.t.u. per lb.; its specific heat is about 0.5. Even if we wished to do so,

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we could not preheat it very much before introduction into the airstream, because such preheating would distill off the lighter fractions and waste them. The latent heat of vaporization must be and should be applied to the fuel as, or after, the mixture is made. One obvious way is to preheat the air; another, to directly heat the charge. However, the heat conductivity of air is so low that, unless these are carried to an extreme which results in substantial loss of power, there is not sufficient time for the necessary exchange of heat between the evaporating fuel droplet or film and the enveloping air current. It can be demonstrated that even in highly heated air a fuel drop of any great size will actually cool off rather than heat up, because the absorption of latent heat in the volatilization of the lighter fractions more than offsets the gain of heat from the air. It can therefore be expected that the temperature of the vaporizing fuel particles themselves, instead of being raised by contact with heated air, may actually be lowered as the evaporation proceeds. From all of the work in our own laboratories on the evaporation of liquids, it seems to me very doubtful whether air heating is of any measurable direct benefit in securing complete evaporation of the fuel. Its indirect benefit is very clear, however, for the heated air heats the walls of the carbureter and intake-manifold and, in this indirect fashion, transmits heat to that unvaporized portion of the charge which separates as a film on these walls.

The direct and logical attack on the problem, however, would appear to be to endeavor to throw the unvaporized fuel particles positively out of the insulating airstream, which effectively prevents them from picking up very much heat in their brief travel from the throttle-valve to the engine valves. If the separating surface upon which they impinge were heated to some high temperature, the higher the better, short of the point at which carbon deposits take place, it would be perfectly feasible to take advantage of practically the full inherent volatility of the fuel. It should be noted that a highly heated separating surface upon which the unvaporized fuel particles impinge does not mean a high manifold temperature. The same insulating property of the air which makes vaporization so difficult to obtain in an old-type manifold also makes it possible to heat a separating surface of limited area on the manifold, such as a hot-spot, to a very high temperature without unduly raising the mixture temperature. I hope I have convinced those

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automotive engineers who may have held a contrary opinion that, so far as the mixture temperature itself is concerned, it is already high enough and that they need not fear condensation, even with fuels much less volatile than those now common.

Apparently the problem which automotive engineers face resolves itself into the further development, improvement and wider use of the hot-spot. I feel that the progress of automotive engineers in this respect has been phenomenal up to the present time. I noticed recently in one of the periodicals an editorial describing a test of a simple form of attachment hot-spot which presumably could be applied to any engine. The test showed that within 36 sec. after the exhaust gases were admitted to the jacket of the hot-spot, the mixture passing the same was perfectly dry as shown by a glass manifold. I once conducted some rather crude tests on a hot-spot of this same design and found that complete vaporization of the fuel was secured in this way with a manifold temperature beyond the hot-spot of 125 deg. fahr. The surface of the hot-spot itself at that time showed a temperature of 350 deg. fahr., as accurately as it could be measured. It is, therefore, apparent that advanced hot-spot design has already reached a point at which automotive engineers can come very close to utilizing the full inherent volatility of the fuel by the simple and logical expedient of directly heating the unvaporized fuel in contact with the air, rather than by trying to preheat the fuel or to heat the fuel by contact with heated air.

It is my hope that some data will have been found in this paper on the physical and chemical properties of internal-combustion engine fuel, from this standpoint of volatility, which will make it easier for automotive engineers to analyze properly the difficulties which they are meeting, and to understand just why and how their most promising mechanical solution of these difficulties operates. This simple solution is not only capable of being incorporated in new designs, but promises to lend itself to attachment to existing engines without great difficulty or expense. Insofar as this proves feasible, we shall apparently be able to perpetuate the mutually advantageous condition of the past, the condition of a single prevailing type of engine in which a single grade of fuel, the cheapest grade, can be used with universal satisfaction. [The discussion of this paper is printed on page 123.]

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FUEL RESEARCH DEVELOPMENTS

By C F Kettering[1]

Two distinct problems are involved in fuel research work, multi-cylinder distribution and the chemical constitution of the fuel mixture after it enters an engine cylinder. In discussing elementary combustion, the author refers to the components of the energy of combustion as gravitational, kinetic and barometric, and elaborates his theme with the aid of diagrams and charts showing normal and abnormal combustion.

After emphasizing the necessity of theorizing at some length, anti-knock substances are discussed, inclusive of substances apparently dissimilar that have the same chemical constituents. The ignition point and fuel utilization are treated, followed by comments upon fuel studies that have been made, with accompanying indicator-cards. The future objectives of fuel research are outlined as being along lines of physical and of thermochemistry, the simple laws of elementary physics, and cooperation with the producers and refiners of the fuel.

In again taking up the subject of fuels, I think that from every standpoint we have made wonderful progress in the past year. The laboratories that have been working on this problem have found out some things and so has the public; the refiners have joined in and I believe that we really have approached a position now where we know approximately what we are talking about. Even if we have not solved the problem, we have at least agreed that the solution we are seeking lies in a certain direction. I believe that we do not realize what a heterogeneous mental attitude we have had.

There is a deadline in the automotive industry. We might just as well recognize it as being our fuel situation. If we can get cooperation between the oil producers and the automotive engineers, so that we may know where that deadline is and so that no one steps over it unintentionally without knowing that it is there, I think we can do some really constructive engineering work. But we must take that deadline into account and know not only the quality of our fuel today and what its local distribution is, but also what its end-point is going to be in 3 to 5 years from now.

Two distinct problems are involved in this fuel work. First comes the question of multi-cylinder distribution.

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I believe that none of us can appreciate just how important a factor distribution is until we have taken a single-cylinder engine, in which the factor of distribution has been eliminated, and experimented with it. When we get the variations in mixture, the power, the temperatures of the cylinder walls and the exhaust, and the temperatures of the water-jackets for lean and for rich mixtures, we will begin to understand what percentage of this problem belongs to distribution and what percentage to the chemical side of it after the mixture gets into the cylinder. We can run a single-cylinder engine economically when the air going into the carbureter is 10 deg. below zero fahr. We can run it at 15 lb. per sq. in. higher compression with air 10 deg. below zero than we can with air at room temperature; and yet, theoretically, we ought to have hot air on that kerosene carbureter. But we discover, as we adjust the carbureter for leanness and richness, that adjustment makes considerable difference from the standpoint of economy, as well as from the standpoint of power. After we get the proper adjustment, we presuppose that, if the carbureter measures off a certain definite and correct amount of fuel, the same correct proportion will land satisfactorily in all of the cylinders of a multi-cylinder engine. So, we have confused the problem of distribution with that of chemical constitution. These two things are entirely different. Usually, what helps the one, makes the other worse, but when they get hitched together, they make a fine pair.

Let us go back and define a few things; our nomenclature has got us into a wrong way of thinking. We talk about heat without having any physical conception of it. According to the best information available today, heat is nothing but molecular velocity. Whether a thing is hot or cold depends only on the magnitude of its molecular velocity. In considering heat we are dealing with motion.

Elementary Combustion

It will be interesting and of assistance in helping us to think about heat as a function of kinetic energy and a function of velocity and motion, to consider a most elementary case of combustion. Fig. 1 is based primarily upon the combustion of hydrogen and oxygen. Suppose two containers, one of hydrogen and one of oxygen, are set alongside of each other. They are at the same temperature. According to the kinetic theory

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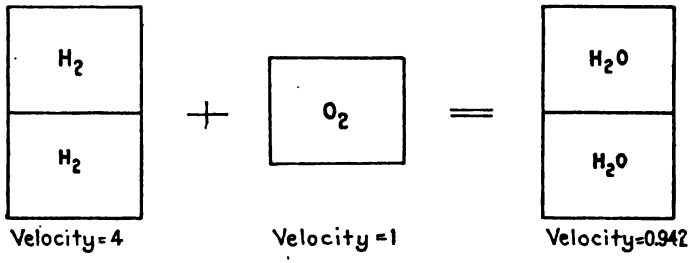

FIG. 1—COMPOSITION OF HYDROGEN AND OXYGEN

of gases, the kinetic energy of the gas inside of a container for a definite temperature and pressure is the same for all gases, and there are the same number of molecules in the container regardless of what the gas is. Let us suppose that two containers of hydrogen gas, which has an atomic weight of 1, or a molecular weight of 2, are alongside one container of oxygen, which has an atomic weight of 16 or a molecular weight of 32. If they have the same amount of molecular energy and an equal number of particles of each are in the containers, the hydrogen gas must move just four times as fast as the oxygen. When combustion occurs, or when the oxygen and hydrogen go together, the hydrogen is slowed down because the heavy oxygen molecule cannot run along with it at its former speed; so, some energy is given up by retarding the velocity of the hydrogen gas. But when oxygen and hydrogen burn and cool back to the temperature at which combustion began, the amount of gas has been reduced. Therefore, some energy has come by a change of volume. But the major part of that energy

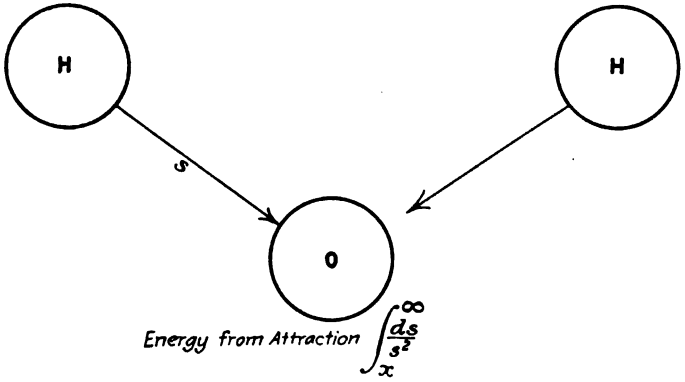

FIG. 2—GRAVITATIONAL ENERGY OF HYDROGEN AND OXYGEN

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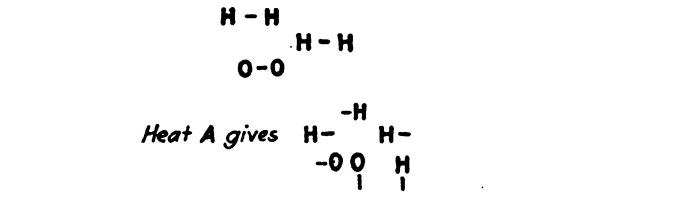

FIG. 3—HEAT OF COMBUSTION OF HYDROGEN AND OXYGEN

has come from another source, that is from the gravitational energy of the hydrogen molecule falling toward the oxygen molecule.

The components of the energy of combustion are

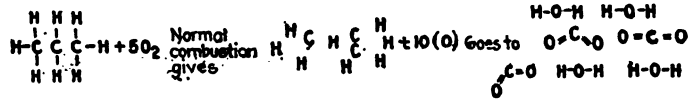

FIG. 4—NORMAL COMBUSTION OF PROPANE

gravitational, kinetic and barometric. It is very interesting to take some of the more elementary combustions and study them along this line. The gravitational energy is the energy which has been liberated by bringing closer together the centers of gravity of the oxygen and hydrogen particles. The kinetic energy is the change in the velocity of motion of the particles. The hydrogen

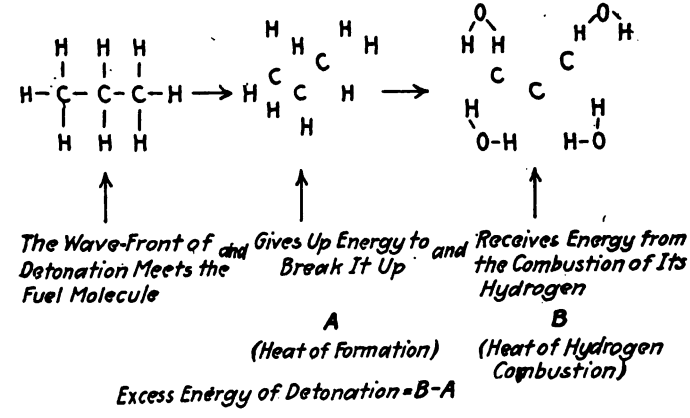

FIG. 5—DIAGRAM SHOWING THE ABNORMAL COMBUSTION OF PROPANE

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was going fast; the oxygen was going slow. When they came together, the total mass slowed down considerably and that gave kinetic energy. The barometric energy is represented by the decrease in volume.

Let us consider an oxygen and a hydrogen particle as shown in Fig. 2 and that they are going to come into combination. A line integral of the distance between them, represented by s, is shown. It approaches from infinity, which is not necessarily very far, because these particles are very, very small and just a little bit is infinitely great. The amount of energy is the same in principle as that of the falling of a stone to the ground and is worked out in the same way. The mathematical formula for energy given in Fig. 2 is just a general expression of gravitational energy. The only reason we cannot figure it exactly is that we do not know the distance between the oxygen particle and the hydrogen particle. When we once get that, we will be able to know specifically what these things are. But we calculate the amount of energy liberated by this new set of static conditions exactly as we would the amount of energy developed from the falling of a stone. If those particles

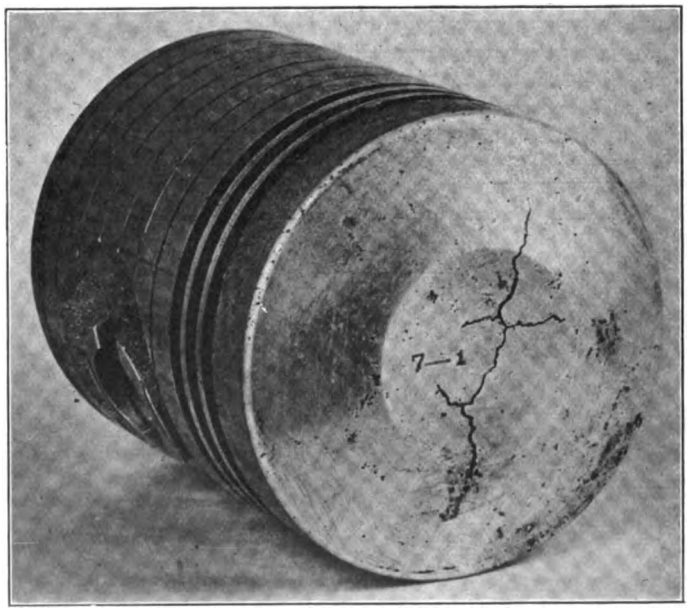

FIG. 6—A LIBERTY ENGINE PISTON, THE TOP OF WHICH WAS CRACKED AS THE RESULT OF BEING SUBJECTED TO EXCESSIVE PRESSURE

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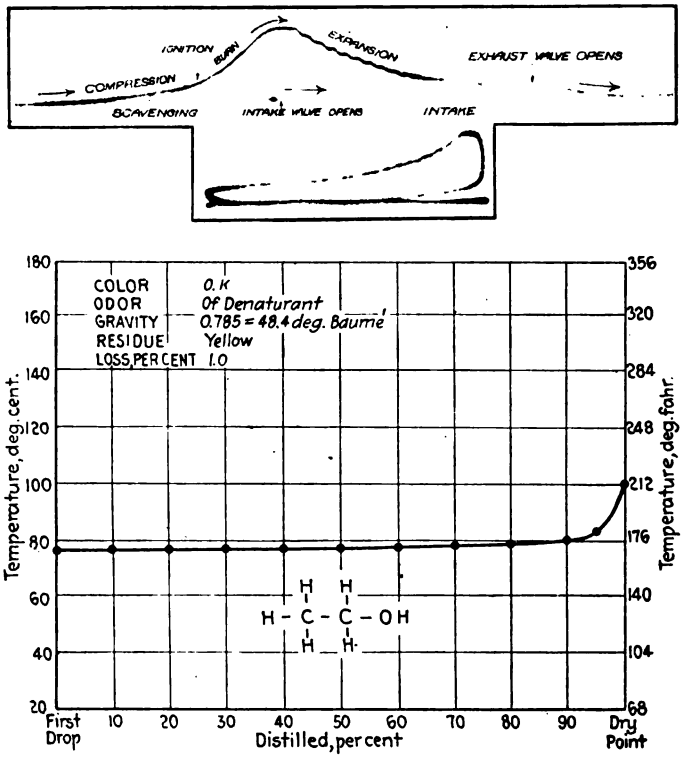

FIG. 7—FUEL STUDY OF COMMERCIAL DENATURED ALCOHOL

cause a great agitation as they come together, that represents heat; it is simply an oscillatory vibration of the particles as they bump back and forth.

Now let us consider the kinetic energy. As we expand a gas, we cool it. When we cool a gas, we simply take the velocity out of the particles. That is the only difference between a hot and a cold gas. If we consider heat as a type of velocity and that an engine is simply transferring molecular velocity of the gases into physical velocity of the pistons and the crankshaft, we will get a much clearer conception of what we mean by thermodynamics. If we boil down all of our present scientific knowledge, we come to a few fairly definite conclusions. One is that all the various phenomena of nature obey a few very simple elementary rules of mechanics. The laws of chemistry and physics and astronomy and all such matters are very delicately interwoven.

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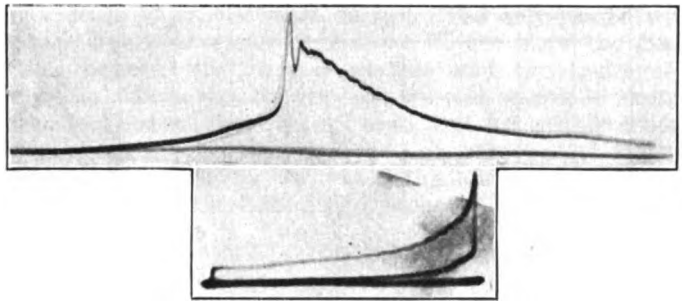
Let us analyze and find out what a charged particle is and what a catalytic reaction is, referring to the kinetic energy of combustion. The sensible heat in a gas is proportional to one-half of the energy, that is, to one-half the mass times the square of the velocity of the molecules of the gas. The various velocities have been measured. The hydrogen has a molecular velocity of 5560 ft. per sec. at 32 deg. fahr. (0 deg. cent.). The oxygen figure is approximately one-fourth of that. The water has a velocity which is the equivalent of the molecular velocity. The values of $\frac{1}{2}\ mv^2$ show us that we have left the difference between the sum total of all the kinetic energies of oxygen and hydrogen and the kinetic



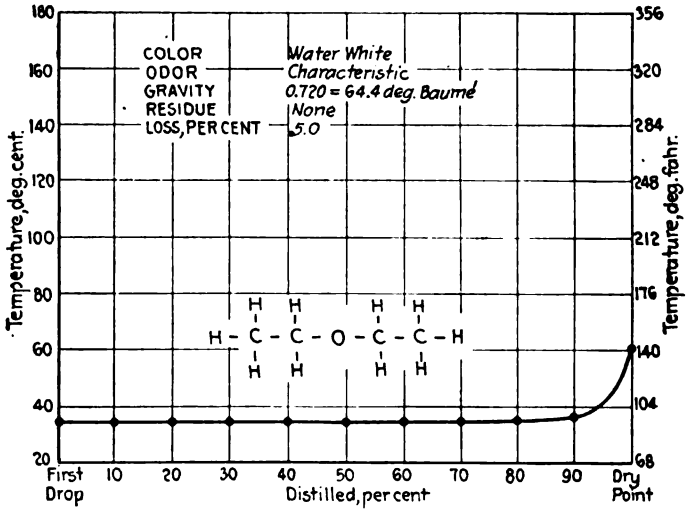


FIG. 8—FUEL STUDY OF SULPHURIC ETHER

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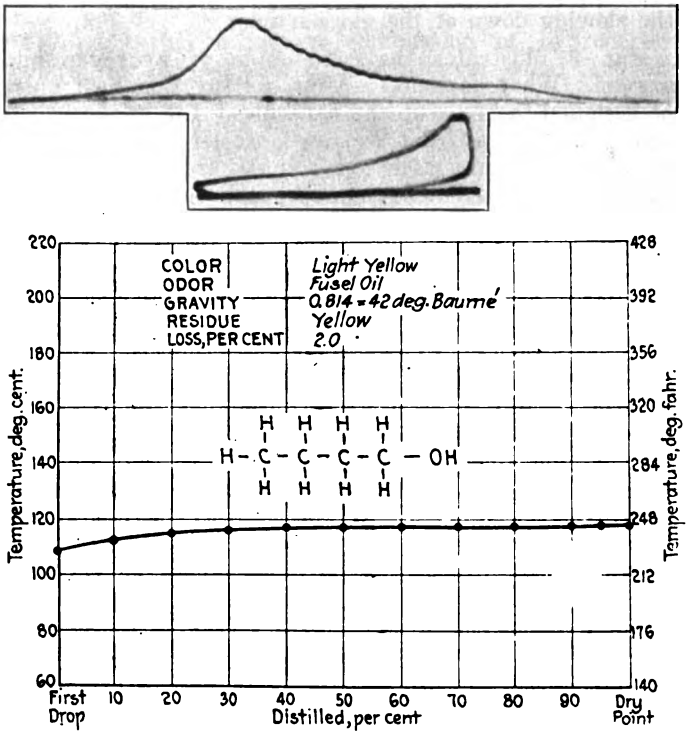

FIG. 9—FUEL STUDY OF BUTYL ALCOHOL

energy of the water vapor. That difference we have taken out is energy, so far as the slowing down of the gas particles is concerned, and that is a sensible amount of heat; it is 305 B.t.u. per lb. of hydrogen.

In reference to the barometric energy of combustion, this is just the difference due to the changing of volume. At 32 deg. fahr. and 14.7 lb. per sq. in. absolute pressure, 1 lb. of hydrogen occupies 180 cu. ft. and 8 lb. of oxygen occupies 90 cu. ft., a total of 270 cu. ft. But 9 lb. of water occupies 180 cu. ft. and the difference between the 270 cu. ft. occupied by the hydrogen and the oxygen and the 180 cu. ft. occupied by the water gives 90 cu. ft. as the reduction in volume upon the combustion of 1 lb. of hydrogen. Completing the analysis gives

$$(90 \times 144 \times 14.7) \div 778 = 245 \text{ B.t.u.}$$

This is the barometric energy of combustion of 1 lb. of hydrogen, and the 245 B.t.u. per lb. of hydrogen is not

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as much energy by about 30 per cent as was caused by the slowing down of the gas particles.

Fig. 3 illustrates the combustion of hydrogen and oxygen. What happens? First, we say that heat must be supplied to break up the molecules. Let us not call it heat. Let us say that we must accelerate the velocity of that hydrogen particle to a point where its acceleration pressures are greater than its attraction. We have things here that are sticking together. We begin to shake the molecule back and forth and reach a point where the acceleration pressures become greater than the force holding the atoms together and they come apart. We have free hydrogen and free oxygen. Heat, *A*, must be supplied to break up the molecules as shown in Fig. 3; these unite and produce heat, *B*. That combination is given energy from the standpoint of kinetic energy, of barometric energy and of gravitational energy. So *B* minus *A*, gives the available amount of velocity or heat that we can use for something else. In this case it is 57,000 B.t.u. per lb. of hydrogen. The result is a liquid; it is water at 64.4 deg. fahr. (18 deg. cent.). I have followed through this rather elementary thing, the burning of oxygen and hydrogen, because I think that we as engineers should get acquainted with the problem in specific application rather than in perfectly general terms. We have been accustomed to putting the charge into an engine cylinder, saying that it exploded, and letting it go at that.

Fig. 4 illustrates the normal combustion of propane, which is a hydrocarbon gas. This is purely a theoretical expression. Instead of having a simple combination of molecular oxygen and molecular hydrogen, we have a combination symbolically represented as shown. This expression does not necessarily represent the facts in the case at all. When the hydrogen and oxygen unite, the same thing happens as when the molecular oxygen and hydrogen became one; so, there is a combination of energy represented here that may be many times greater than the simple energy of the hydrogen-molecule or oxygen-molecule combination. If we were using propane in an engine cylinder, the first thing we would need to do when a spark is put through it is to supply enough motion to that molecule to shake it apart, so that it becomes free hydrogen and free carbon. In the presence of oxygen, new gravitational conditions are set up and there are tremendous disturbances which we call heat.

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Calculating as before, the heat of combustion is 20,000 B.t.u. per lb.

We call that a normal combustion of hydrocarbon where the oxygen and hydrogen form water and the carbon and oxygen carbon dioxide. There is a condition under which we can bring oxygen, nitrogen and hydrocarbon together, where we do not get the perfectly normal combustion that results in water and carbon dioxide, but where the rapidity with which we accelerate these things is so great that we burn only a part. It is something like a load of bricks on a wagon; when we check the wagon too quickly the bricks slide off. In the case of an abnormal combustion, we start the one particle so fast that the other cannot follow. Then we get an entirely different result. In the abnormal combustion shown in Fig. 5, we get a much smaller amount of heat with the liberation of free carbon, instead of getting a large number of heat units as before. If we put propane

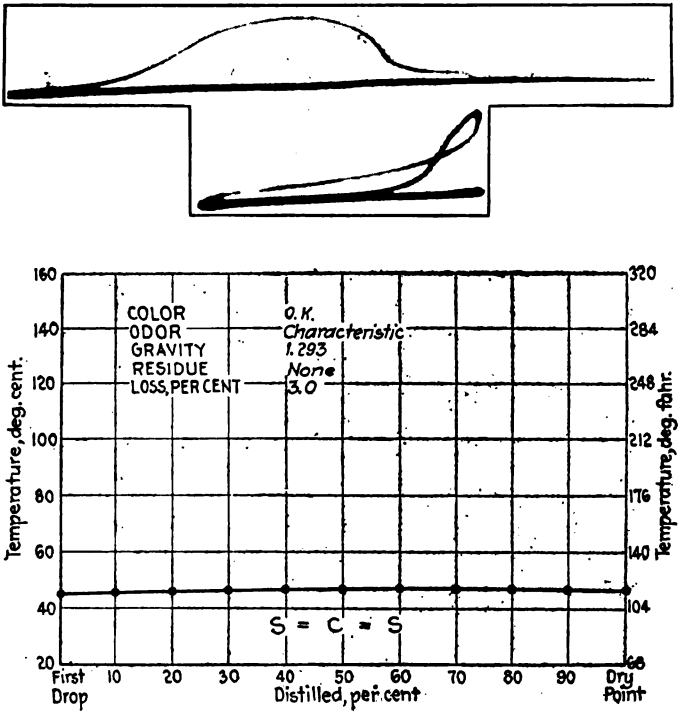

FIG. 10—FUEL STUDY OF CARBON BISULPHIDE

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gas into an engine, we would never get a condition of abnormal combustion such as this, nor would we get a knocking condition, because we would have in the engine a diluting element in the form of nitrogen gas. But if we change the mixture, if instead of air and propane in the engine cylinder, we throttle out the nitrogen and begin to let into it a little oxygen, we immediately meet the abnormal condition shown in Fig. 5. So, no matter how excellent the specific gravity of the fuel is, we can always reach an abnormal condition with it by accelerating the combustion.

The Necessity of Theorizing

The matters I have explained thus far relate to the elementary mechanics of combustion. Any thermal chemistry contains the same information; there is nothing new about any of it. There is no trouble in getting this information; the trouble has been in the nomenclature which has been used. We use the terms "heat" and "light" without having a physical conception in our minds as to what these things really mean.

The theory of all of this may be 100 per cent wrong, but that makes no difference. If we never had theories about things, we would never arrive at radical results. To illustrate, Mr. Midgley and I had the very beautiful theory that what causes kerosene to knock is that it enters and becomes vaporized due to the heat that is in the cylinder when it comes in, and that when compression begins, the heat of compression does not develop fast enough to keep the kerosene from liquefying again and the mixture slows down to a point where the kerosene forms in little particles on the cylinder wall. We knew that early spring flowers are red on the bottom of the leaves, so as to utilize the maximum amount of radiant energy from the sun and get a little more heat. Therefore, we concluded that if we dyed fuel red it would absorb more energy and consequently not condense so easily. The chemical laboratory had no oil-soluble dye, but it did have iodine. Iodine colored our fuel red and that was all we wanted. The iodine stopped the knock, but it did not stop the knock because it was red. However, if we had not had that theory we would never have found out about these matters. So, I think we ought not to criticize a man for having a theory. If he has no theory, he will not progress very far.

We know that very definite chemical laws govern existing fuels and that many things can be done in making use

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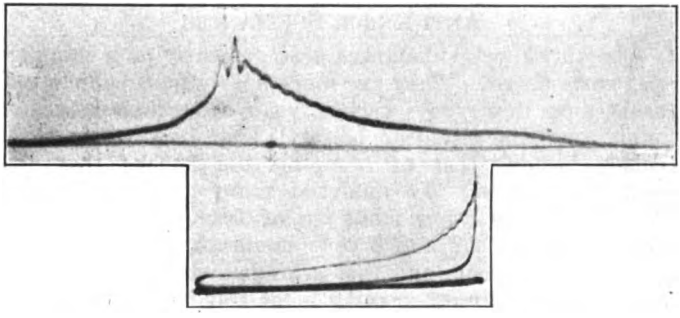
of them. This subject is presented with the idea of laying before automotive engineers what we have found out and what we are thinking about. We realize that we are so inadequately equipped, mentally and physically, to cope with all the ramifications of this problem, that we need to show the progress made from year to year and to get all automotive engineers to think along this same line. It makes no difference whether a single thing I



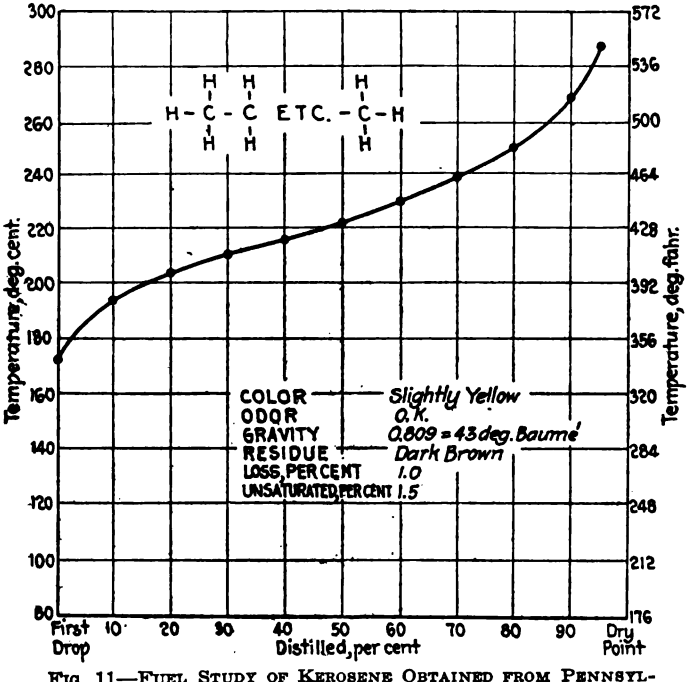


FIG. 11—FUEL STUDY OF KEROSENE OBTAINED FROM PENNSYLVANIA CRUDE OIL

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have said is right or wrong. If I can convey the point of view of realizing that this problem exists, I shall be satisfied. I have been accused recently of trying to rewrite the theory of explosives. We are not trying to rewrite anything; we are simply trying to utilize facts. We know that engines knock. That is not a theory any more. It is a fact that we get crankcase dilution. We simply try to take the facts, analyze them, find out the cause and determine what can be done to eliminate it.

Anti-Knock Substances

The anti-knock substances are not nearly on a commercial basis as yet. They are more nearly on a commercial basis now than they were a year ago, because people understand the situation better. They have many other values besides that of stopping the knock; they are carbon solvents. We analyzed many carbon deposits. We found they were made up of free carbons, a very heavy hydrocarbon and a very small amount of a hydrogen-oxygen carbon, and that a binder which is about the same as an ordinary varnish holds this hydrocarbon and the free carbon together. It happens that these anti-knock substances are all varnish-removers; consequently they dissolve out the binder part of the carbon deposits and the remainder blows away.

There are many theories regarding detonation. Fig. 6 shows a piston taken out of a Liberty engine; the top is cracked. We have seen some pistons, worse than this one, that have been blown in. We do not know what hit the piston; an explosion-wave or a detonation. The fact is that the piston was knocked in.

Difference in Molecular Structure

We have a number of apparently dissimilar substances that have the same chemical constituents. Ordinary rubber, such as is used in automobile tires, and naphthaline are two apparently different substances. One is a very tough, tenacious material and the other is a crystalline substance; but each is composed of hydrogen and carbon. I mention them to show that the same two things can be put together in such ways that their molecular constitutions are enormously different. Another instance is that of two liquids, benzol and cyclohexane, the latter being nothing but benzol with an added amount of hydrogen.

The crystalline substances, naphthaline, rubber, and paraffin, which is a more or less amorphous form of

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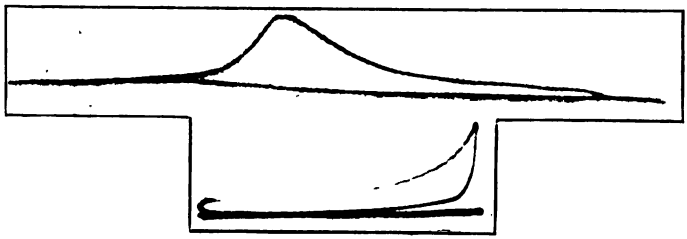
hydrogen and carbon, are all the same; they are just made up in different combinations. That is why we must realize that the chemical constitution of fuels represents so many different things.

Ignition Point and Fuel Utilization

There has been much discussion as to the ignition point. The autoignition point is only the point at which we reach the proper condition of molecular velocity; it has absolutely nothing to do with the phenomenon of



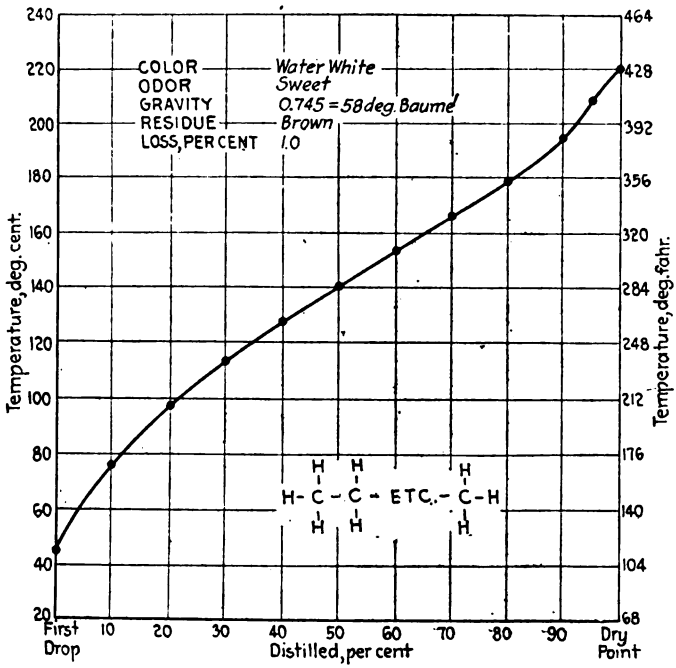


Fig. 12—Fuel Study of Gasoline Obtained from the Same Pennsylvania Crude as the Kerosene of Fig. 11

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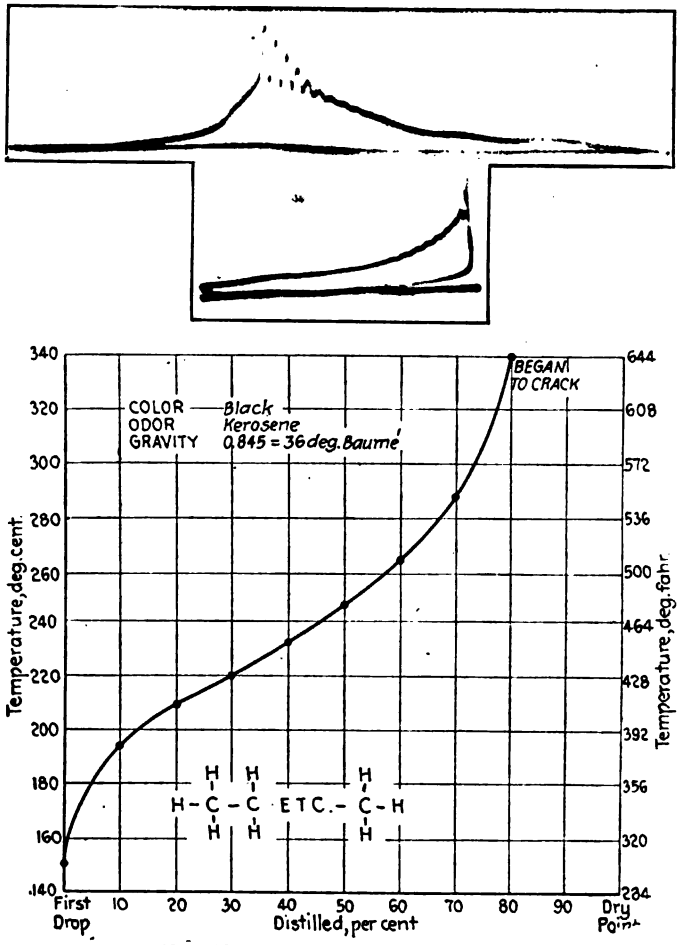

FIG. 13—FUEL STUDY OF FUEL OIL

knocking. Carbon bisulphide has such a low autoignition point that we can heat it with a hot wire and explode it. If we put that into an engine, it absolutely will not knock, and yet its autoignition point is only 140 deg. So, autoignition, or preignition, has absolutely nothing to do with the phenomena we are talking about.

The question of the utilization of fuels today involves two distinct things. One is the matter of getting the right mixture into the cylinder. This has no relation to the physical constitution of the fuel, except insofar as it is hard to segregate and nebulize to get the right amount

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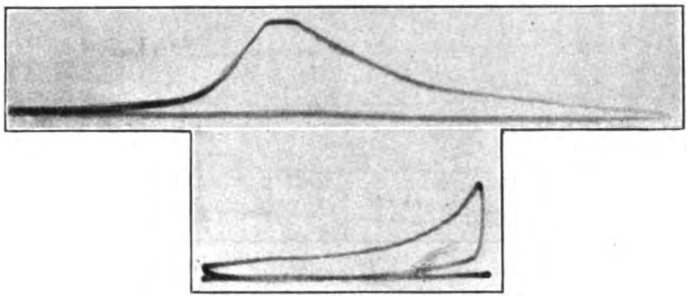
by weight of fuel and air into each cylinder. After experimenting with a single-cylinder engine, the very distinct conclusions are reached that it makes no difference whether the fuel goes in as a dry gas, a nebulized gas, a vaporized gas, or any kind of gas; that if we get the right weight of fuel and air into the cylinder the mixture will burn under certain definite conditions; that the conditions under which that fuel burns are a function entirely of its chemical constitution; that abnormal combustion, which we term "knocking," is an entirely different phenomenon from preignition; and that the auto-



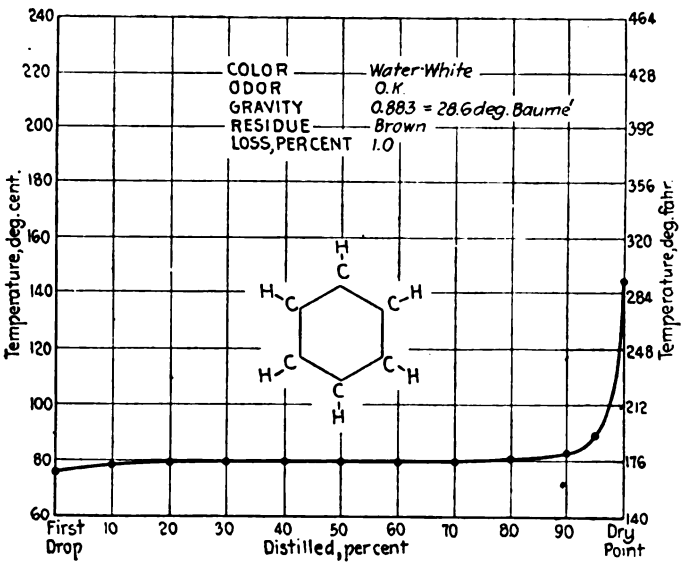


FIG. 14—FUEL STUDY OF COMMERCIAL BENZOL

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ignition point of a fuel may or may not have something to do with its knocking ability.

If we can only get it into our minds that we should quit thinking of heat in any other terms than those of molecular velocity, we will have helped ourselves one step farther along in our ability to realize and to bring together the loose ends of the fuel problem. All of the phenomena of physics and chemistry can be utilized in engines. It is only because we perhaps have not had to analyze the details of these operations, more than was necessary at the beginning of the automotive industry,

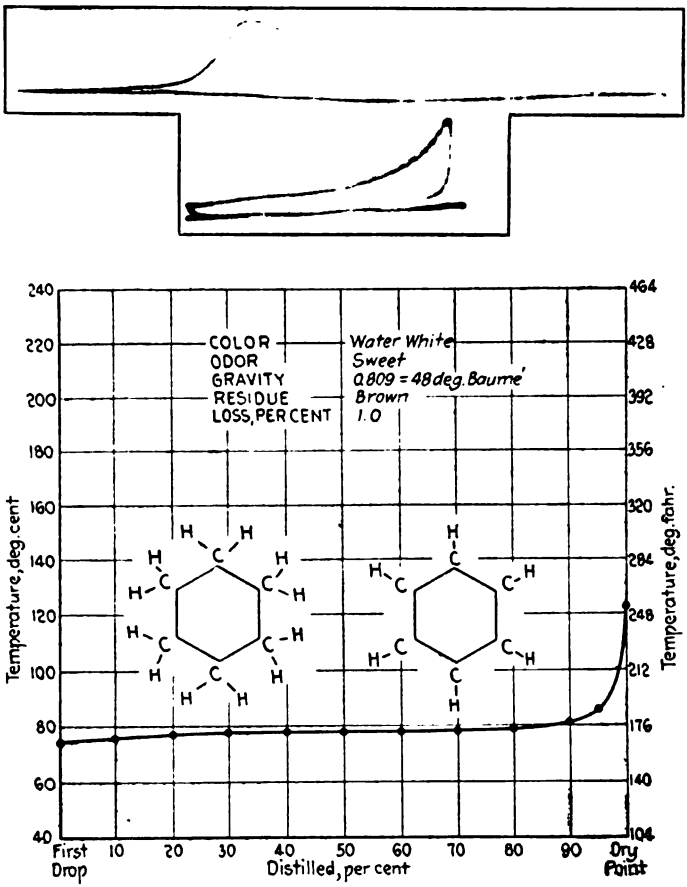

FIG. 15—FUEL STUDY OF A MIXTURE COMPOSED OF 80 PER CENT CYCLOHEXANE AND 20 PER CENT BENZOL

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that we have forgotten them. That has been perfectly natural in the development of this business. In the early days we had fuel of a high volatility. All that was needed was to make true engine cylinders, well fitted pistons and valves and then install almost any type of mechanism to supply the fuel. The engine ran very well. The volatility of the fuel began to drop and we began to work to overcome the attendant difficulties. When we break a crankshaft, we take it to the chemical laboratory,

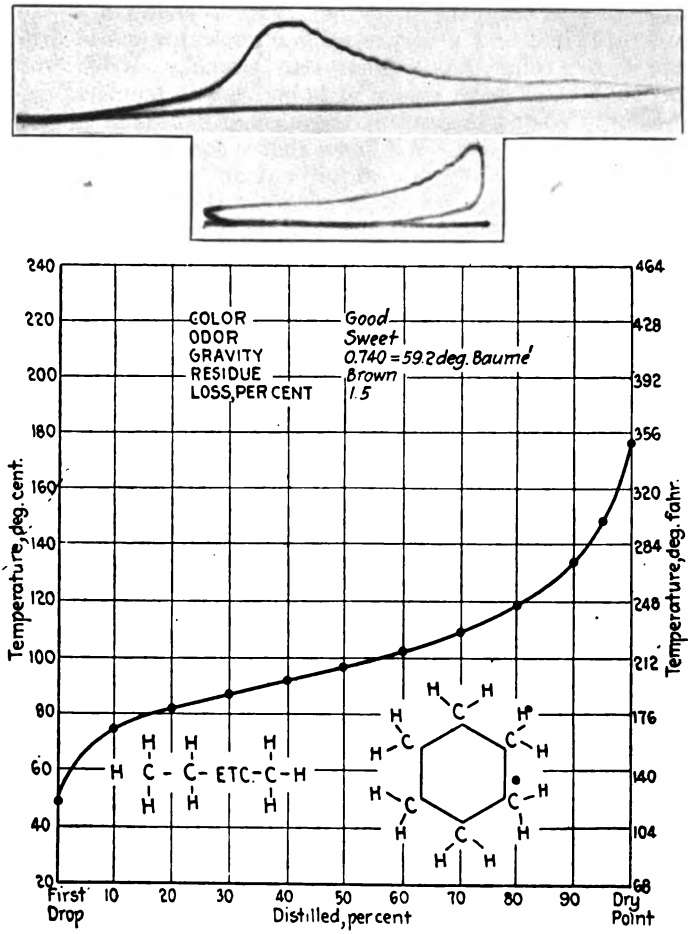

FIG. 16—FUEL STUDY OF A GASOLINE OBTAINED FROM A CALIFORNIA CRUDE OIL

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have it analyzed, see whether the chemical composition is right and then trace the heat-treating. We should apply the same study and method to the fuel theory that we have applied to the heat-treating theory.

The indicator cards produced by the different fuels are shown in Figs. 7 to 16. Fig. 7 shows the distillation curve of a fuel as determined by the standard method given by the Bureau of Mines. The distillation curve shows the temperature at which a fuel evaporates. It is a function of the size of the molecule and is only an easy way of weighing the molecule. Fig. 7 shows also the pressure-time and pressure-volume indicator cards produced by commercial denatured alcohol. When the alcohol goes off with a very little increase in temperature, it simply means that all of the alcohol molecules are of about the same size. We know that when water reaches 212 deg. fahr. it all goes off without an increase in temperature. That is simply a proof of the fact that the molecules are the same size. The upper card shows the type of curve produced when alcohol burns. The lower card shows the pressure-volume curve.

Fig. 8 is a fuel study of sulphuric ether. It is shown to demonstrate that volatility has nothing whatever to do with knocking. It is a very volatile fluid and a beautiful knocker. It has a very low vapor-point, and this shows that specific gravity has nothing to do with the knock.

Fig. 9 is a study of butyl alcohol. It does not have so good a distillation curve as sulphuric ether, but has the same general explosion and gives no detonation.

Fig. 10 shows a carbon bisulphide study. It exhibits very bad preignition, so that the pressure-volume loop, where it comes back on itself practically, can be seen; yet it produces absolutely no knock.

Fig. 11 shows kerosene and Fig. 12, commercial gasoline from the same Pennsylvania crude. We can see what is meant by abnormal combustion. The distillation curve starts way up.

Fig. 13 is a study of fuel oil. It is a little farther down the scale. Fig. 14 shows benzol. The curve comes up and flattens off nicely. That flat top is the thing that we must get with gasoline. Fig. 15 shows a mixture of 80 per cent of cyclohexane and 20 per cent of benzol. Fig. 16 shows California gasoline.

Table 1 gives the excess energy liberated during detonation. We took a cubical content of fuel mixture that

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would give ether a value of 1000, paraffin 860, olefin 805, naphthaline 780, aromatics 545 and alcohol 620. The anti-knock substances are simply things that, put into the fuel, will absorb that excess energy.

TABLE 1—ENERGY LIBERATED DURING DETONATION

Fuels	Excess Energy Liberated During Detonation
Ethers	1,000
Paraffins	860
Olefins	805
Naphthines	780
Aromatics	545
Alcohols	620

Future Objectives

I hope to interest automotive engineers enough in knowing that there is a road by which physical chemistry, thermo-chemistry and the simple laws of elementary physics can help take this apparently complex combustion problem and analyze it so that we can understand what happens and work better with the people who are producing our fuels to find out whether they can better adapt or better fit them to the machines in which they are to be used. That is the viewpoint that automotive engineers should have. These matters are important. The fuel economy of our motor vehicles must be improved. We must burn less fuel per car-mile. We must reduce the mechanical friction. If we should use measuring apparatus, we might find that it takes more power to turn the engine than it does to run the automobile. The engine frictions are excessive. Engine friction today is one of the biggest problems we have; it can do much to prevent the attaining of adequate fuel economy. A better understanding of fuel combustion will help us to build better and more economical engines.

The Bureau of Standards is doing much good work. Let us utilize all this and take advantage of the Society meetings as occasions to report progress and assemble our data. It is only by reporting on progress and talking matters over that we will attain the desired results. Each year we find we have progressed somewhat. In any new problem the increment of progress is relatively small. That is true of the growth of any business. [The discussion of this paper is printed on page 123.]

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NEED FOR RESEARCH ON AUTOMOBILE PARTS

By William T Magruder[1]

The time has come when greater attention must be given to the smaller parts and the various appliances found on automotive machinery. Previously, investigations have been made by the research laboratories of a few companies manufacturing engines, carbureters and some other parts, but chiefly engines; by the laboratories of research corporations, including the Bureau of Standards and the Bureau of Mines; and by the engineering laboratories of colleges and technical schools.

The number and value of the researches that can be conducted and reported on from time to time by these agencies depend entirely upon the appropriations that they can obtain by act of legislation and upon the personnel of the staff that can be attracted by the opportunity to do this class of work. It would therefore seem to be to the interest of automotive engineers to advance the research work being done by Federal and State institutions, to see to it that adequate appropriations are made by Congress and the State legislatures and that those problems which need solution are attacked according to a guided program.

The author gives an account of engine tests made at Ohio State University, inclusive of considerable information regarding the kind of research, methods, equipment and results. A further series of tests to determine the power lost in transmission is described and commented upon in a similar manner, and mention is made of a series of tests which it is proposed to conduct to determine the power required to drive a car at different speeds.

The work of automobile testing laboratories has largely followed the example set in the last 40 years by steam-power laboratories. Tests on engines and materials have become common, while high-grade tests of fuels have been made only in a very few research laboratories. Tests on some one appliance have been made and the results buried and forgotten in the archives of the manufacturer of the particular appliance without their being made known to the automobile world. The time

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has now come when greater attention must be given to the smaller parts and to the various appliances found on automotive machinery.

Previously investigations have been made by the research laboratories of a few companies manufacturing engines, carbureters and a few other parts, but chiefly of engines; of research corporations, including the Bureau of Standards and the Bureau of Mines of the Federal Government; and of the engineering laboratories of our colleges of engineering and technical schools. It is hardly to be expected that private research laboratories should give to the world, even through this Society, the results of experiments which have cost from one to several hundred thousand dollars per annum, although it must be admitted that they have erred on the side of generosity rather than of selfishness in this regard. The number and value of the researches which can be conducted and reported on from time to time by Federal and State-supported institutions and universities depend entirely upon the appropriations that they can obtain by act of legislation and upon the personnel of the men attracted by the opportunity to do this class of work.

Research work in the engineering laboratories of State universities is done either by the instructors for their own interest and pleasure or for their clients, or by the students as thesis work under the direction of one of the instructors. For these purposes, manufacturers are usually very generous in supplying material, if the laboratory will supply the testing equipment, fuel and labor. The colleges are glad to get this assistance even if the agreement is not always 50-50, and more frequently is 20-80, as it keeps them in touch with the manufacturing world.

Engine Tests at Ohio State University

In the last 20 years a number of tests of automotive machinery and parts have been made in the Mechanical Engineering Laboratory of the Ohio State University. It is thought that an outline of some of these tests may be of interest to the members of the Society in connection with this discussion of the subject. The friction of an engine can be determined by running the engine under load, absorbing the power by an electric dynamometer, and, when it has become thoroughly heated up, closing the throttle and carbureter valves and driving the engine from the dynamometer as a motor, and measuring the power required to drive the engine at various speeds,

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with and without the magneto, fan, valve-gear, or pistons. For example, it is of interest to learn that it requires about 2.5 hp. to drive a Ford engine at 700 r.p.m.; 3.0 hp. at 900 r.p.m., or at 22 m.p.h.; 3.5 hp. at 1000 r.p.m.; and 4.2 hp. at 1100 r.p.m., without current being generated by the magneto. With current from the magneto, from 0.2 to 0.3 hp. additional is required. That these results are low, as should be expected, as compared with the frictional horsepower developed when the engine generates its own power, can be shown by the statement that the frictional horsepower of a Ford engine, as determined by a number of different operators, varies from 4.5 to 4.7 hp. at speeds of from 800 to 900 r.p.m. These results were obtained by equating the pounds of fuel per indicated horsepower per hour at a given speed and for different loads, where the indicated horsepower is the sum of the measured brake-horsepower and the unknown frictional horsepower, and solving for the frictional horsepower. With this figure available, the mechanical efficiency of the engine can be obtained with an accuracy depending upon the accuracy of the work and the correctness of the assumption, and will vary with the newness and tightness of the parts and how well they have been run-in.

The temperature of the jacket water of a certain water-cooled, four-cylinder engine was found to have a very decided effect upon both the operation and the power of the engine. Due to the intake mixture being preheated by partial contact with the exhaust manifold, preignition began, with gasoline as the fuel, when the inlet jacket-water reached a temperature of 175 deg. fahr., became excessive at 190 deg., and caused a great reduction in power when the inlet water was 210 deg. The radiator cooled the water only by virtue of the fan and not by the car passing through the air, as in practice. By passing cold water in at the top of the radiator and drawing some of the warm water off at the bottom, thereby keeping the temperature of the outlet cooling water at 150 deg. fahr., it was possible to increase the power of the engine from 17.26 hp. to 18.26 hp., while increasing the gasoline consumption from 0.669 to 0.685 lb. per hp-hr. With kerosene, preignition began at 135 deg. fahr. By excess cooling, the maximum horsepower of the engine with kerosene under normal conditions was increased from 16.67 hp., using 0.890 lb. per hp-hr., to 19.36 hp., using 0.910 lb. per hp-hr. Excessive use of fuel caused

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this engine to give 18.41 hp., using 1.520 lb. of gasoline per hp-hr.; while with kerosene the maximum power was increased to 19.40 hp. when using 1.436 lb. per hp-hr. This means that 61 per cent more kerosene used gave 16.1 per cent more power, and that 127 per cent more gasoline used gave 6.6 per cent more power.

The maximum horsepower of this engine was 22.64 at a speed of 1043 r.p.m., when using 1.110 lb. of kerosene per hp-hr., and 21.07 hp. at 1020 r.p.m., when using 0.725 lb. of gasoline. The use of an excessively hot manifold on this engine caused the maximum horsepower to change from 21.6, when the manifold was cool, to 16.1 hp. when the manifold became heated. This is a change of 5.5 hp., or a drop in power of 25 per cent. These results may be due in part to the tests being made in an open laboratory rather than on the road, but they seem to point to the desirability of having larger radiating surface than was provided with this engine. Again, numerous tests go to show that the proper jacket-outlet temperature for maximum power and minimum fuel-consumption is a function of the shape and fit of the pistons and rings and the thickness of the jacket-water space.

Power Tests

The power lost in the transmission has been determined in this laboratory in two ways. The first is by measuring the speed-drop for increased loads for fixed settings of the carbureter needle-valve, throttle-valve, timer, and other variables, and noting the decrease in speed when power was delivered through the transmission, rather than by the engine direct. By this method, the speed of the engine dropped from 900 to 869 r.p.m., corresponding to 1.35 hp., when the fan was used; and from 900 to 769 r.p.m., corresponding to 3.30 hp., when the transmission was used. Second, by comparing the horsepower delivered by the engine alone to the horsepower delivered through the transmission to the belt-pulley of the tractor, and measured by the brake pulley, the loss between the engine and the pulley was found to be 3.25 hp., or 16.75 per cent of the maximum normal power of the engine. This result checks quite closely with the former. A third method, not yet used, is to insert a torsion dynamometer between the transmission and the differential, or between the engine and the transmission, when this is possible.

The power delivered by the rear wheels is best measured by mounting the machine on calibrated dynamo-

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meter brake-drums. When the rear wheels are replaced by special brake pulleys, an unknown allowance should be made for the frictional load due to the weight of the car on the wheels. A third way that has been tried with fair satisfaction is to replace the rear wheels by sprocket wheels and drive the chain pinions on the ends of the electric dynamometer shaft by chains or link belts. In this case what is measured is not the power delivered by the wheels, but the power delivered by the chains, and this varies with different speeds and loads. When due allowance is made therefor, very satisfactory results can be obtained in measuring the power required to drive certain parts under a variety of conditions, including those with and without compression in the cylinders. A fourth method, usually used in tractor testing, is to absorb the power from the belt-pulley delivered by a belt to an absorption dynamometer. As in the previous cases, allowances must be made for the power required to drive the belt and the dynamometer at different speeds, at initial tensions and whether the belt is open or crossed. In tractor plowing under quantitative test conditions, it has been noticed that only a small decrease in speed will cause the sod to be turned over very differently and without being pulverized, so that a difference of 10 per cent in speed will turn good plowing into bad.

Springing of the Chassis

We have been prevented financially from testing a motor car under its own power when mounted on calibrated dynamometer brake-drums having very irregular surfaces, simulating the effects of cobble-stones on the springs, and measuring the power required to drive the car at different speeds on brake-drums of varying roughness. In the scheme proposed, rays of light were to be reflected from mirrors on the wheel hubcap and on some part of the car above the springs, and received on sensitized paper, to show the relative motions of the two parts of the car. [The discussion of this paper is printed on page 90.]

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AERIAL TRANSPORTATION AS A BUSINESS PROPOSITION

By Glenn L Martin[1]

Aviation has no perfect analogy, for it has no precedent. Two classifications are made. Scheduled service includes the carrying of mail, express or passengers on a definite and regularly maintained schedule, independent of, or supplementary to, other forms of transportation. Special service includes pleasure flights, oil-field survey, selecting industrial land-sites, planning cities, aerial photography, forest-fire patrol, visiting remote points, exploration, aerial advertising, delivery of perishable products, real-estate survey and industrial purposes. Each of these classifications requires different equipment, organization and operating personnel.

The equipment requirements and the reliability of aerial transportation are discussed, the necessity for suitable terminals and federal flying regulations are emphasized, the subject of insurance is commented upon and the development of aerial commercial transportation is outlined. Recent statistics regarding European air travel are quoted.

Aerial transportation includes the use of airships as well as airplanes, but in this paper I will confine my discussion principally to the commercial use of the airplane as a vehicle of transportation. In discussing the subject of aerial transportation, one is apt to lapse into analogies and comparisons with the railroad, the motor truck or the steamship, but as a matter of fact aviation has no perfect analogy, for it has no precedent. There is much that can be learned from railroad, motor-truck and steamship transportation that is helpful in aerial transportation, but the man who thinks he can apply the same rules to commercial aviation will arrive at a very sad misunderstanding.

Aerial transportation is a wholly new business, unlike any other form of transportation. It is a new industry which is really in its embryonic stage, an industry that demands high standards of personal efficiency in the men who are engaged in it. In considering the function of aerial transportation, let us, for the sake of clearness,

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divide it into two distinct classifications; scheduled service and special service. By the first I mean the carrying of mail, express or passengers on a definite and regularly maintained schedule, independent of or supplementary to other forms of transportation. Special service includes pleasure flights, oil-field survey, selecting industrial land-sites, planning cities, aerial photography, forest fire patrol, visiting remote points, exploration, aerial advertising, delivery of perishable products, real estate survey and industrial purposes.

The Two Classes of Service

It is to be understood that each of these two classifications of aerial transportation requires different equipment, organization and operating personnel. A scheduled service, to be of true commercial value, must be faster than any competing form of transportation and operate on schedule. Aircraft capable of at least 100 m.p.h. are therefore essential, and flights must be conducted regardless of weather conditions. Weight-carrying capacity must be sacrificed for greater speed. Since the efficiency of a service of this nature requires the very best design of aircraft, operated by a highly efficient personnel, rates naturally must be high. A scheduled service, properly organized and efficiently operated in stages of from 300 to 500 miles, should average at least 80 m.p.h. in spite of wind and weather conditions.

The most striking example of this class of service is the London-Paris Air Express. The company operating this closed its first year's service on Aug. 25, 1920, with a record of 323,355 miles flown at an average speed of 100 m.p.h. Of the 1535 flights scheduled for the year, 1448 were finished *on time*, while 83 were prevented by weather and four trips were delayed by mechanical defects but were later completed after repairs had been made. Harry Harper, technical secretary of the Civil Aerial Transport Committee in England, declares that one should lay stress on the fact that the conditions for flying are probably worse on this particular route than almost anywhere else in the densely inhabited parts of the world. Yet in spite of this weather handicap the London-Paris Air Express has an efficiency record of 94 per cent for the first year of service.

A special service does not make such high demands as a scheduled service. Speed is not so highly important and the weight-carrying capacity can therefore be increased considerably. Moreover, the maintenance of a

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schedule is unnecessary, and as for weather conditions it is quite possible to wait for weather. Before the day of the airplane the forest ranger was the sole means of detecting forest fires. His means of locomotion was his horse, and usually he was unable to report a fire until the conflagration had gained headway and thousands of dollars were lost before any combative measures could be taken. During 1919, it has been estimated, approximately 2,900,000 acres of National Forest lands were destroyed by fire; the damage represented a net loss of $4,500,000 and a cost to the Forest Service of $3,000,000 for fighting fires. Forest fires are now located by airplane. The picturesque figure of the forest ranger, riding furiously on horseback to give the alarm, is a thing of the past. Since the establishment of the Aerial Forest Patrol on June 1, 1920, the fire hazard has been practically eliminated. Seventeen airplanes were used for fire patrol work. They covered 235,724 miles in 2872 hr. and were instrumental in putting out 570 fires in California and Oregon. There was only one fatality on all these patrols, and only eight accidents necessitated major repairs on the planes.

Scheduled service and special service have one basic problem in common, the distance it is profitable to fly without landing for refueling. It is quite clear mathematically that a cruising radius or operation stage of over 500 miles for an airplane demands the carrying of a large amount of fuel at a great expense and sacrifice of cargo capacity. Airplanes at the present time are short-distance vehicles. Their prime advantages over airships are their speed and flexibility. Where long nonstop flights of 1000 miles and more are required, the airship, with its greater lifting capacity is, of course, decidedly more suitable. Where long-distance flights are required of airplanes, landings should be made every 300 to 500 miles for refueling. Thus it is obvious that airplanes and airships are in no way rivals at present.

Reliability of Air Transportation

Many business men believe that, from a business point of view, aerial transportation is unreliable as well as extremely expensive. Any unreliability that may exist in aerial transportation is dependent upon three factors.

(1) The operating personnel
(2) The airworthiness
(3) The weather conditions

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In railroad, motor-truck and steamship transportation many mistakes which are errors of the personnel or its faulty organization, causing accidents or delay, get by the press with only a stick of type. Most cases are even unnoticed. In aerial transportation the story of one interrupted flight, if it results in an accident, is published in bold-face type from coast to coast. Without federal legislation operating personnel and ground organizations which are wholly incompetent to operate successfully will be hurriedly put together, even though the airplane equipment is of the best. The administrative force should be composed of men who speak and think in the language of aeronautics. With the proper organization and administration of pilots and mechanicians, there is no doubt that personal error can be reduced to a low minimum.

In considering the airworthiness of an airplane as the basic unit of aerial transportation, it is well known that until recently airplanes employed in commercial service were discarded war material, unsuitable for civil purposes. Today, however, the designing and construction of both engines and airplanes have reached such a high state of commercial adaptability that with proper organization and maintenance mechanical breakdown should seldom, if ever, occur. I do not say that the commercial airplane has reached the acme of perfection, for there is yet much to be accomplished in the improvement of both airplanes and airships. Nevertheless, the London-Paris Express Service has flown over 300,000 miles, often under conditions that have imposed severe strains on the machines as well as on the pilots, with only four interruptions caused by mechanical defects.

Weather conditions are a factor in aerial transportation over which the operative personnel had, until recently, very little direct control. In the early days of flying no aviator would think of flying in wind or storms; a perfectly calm day was necessary before he would soar into the atmosphere. In those days, of course, the airplane would not weather wind and storm, but the modern airplane will fly through wind, storm, rain or snow. There are two elements, however, which must be conquered, low clouds or fog and darkness. The difficulties involved are the possibility of losing the course of flight and the chance of misjudgment in landing. Airplanes and airships are now being fitted with directional wireless by which the pilot can ascertain his exact position at all times. Within a reasonable period of time night

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flying will be as common as day flying, fog and low-cloud hazards being negligible.

TERMINALS

With the very best design of commercial airplane and the most highly efficient organization and administration, aerial transportation can go no farther than its terminals. The need for aerial terminals, municipal airdromes, is acute in the United States. The builders are producing airplanes; the engineers are working on improved types of commercial planes; transportation companies are organizing all over the country, and yet to what avail? Aerial transportation will never become universal until each and every community provides an air terminal equipped with proper facilities. Communication by wireless, telephone and telegraph should be provided, as well as rail and motor-vehicle transportation for passengers and freight, hangar accommodations, repair service and stores, gasoline, oil and sundry supplies. The progressive cities in the United States have already awakened to the fact, and I am sure the laggers would follow suit if they only realized that they are mortgaging their future by failing to grasp the tremendous advantage of being on the "main air-line." What would Chicago be, for example, if she had not been the first to recognize the possibilities of her geographical situation? A mere hamlet, or perhaps a port of minor importance. Chicago did not let opportunity knock unanswered at her door. She developed her harbor facilities and is now the biggest port on the Great Lakes, and the second largest city in the country. In the same way aerial navigation will transform many an unimportant village and bring towns out of humble obscurity into the limelight of commercial prominence.

FEDERAL FLYING REGULATIONS

The next point I want to take up is the need of federal flying regulations. America has not yet made a beginning in this direction. Several State legislatures have passed laws providing for the regulation of air traffic within their borders, but the range of the airplane is so unlimited that the legislation of a great number of individual States would lead merely to hopeless confusion. Federal legislation is the only solution. It should not only regulate aerial traffic but provide uniform regulations for licensing pilots and aircraft, and periodic inspection of aircraft and landing fields. Other forms of transportation are inspected. Our steamship and rail-

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road lines are made to conform with certain standards of safety before they are allowed to carry passengers; why not aircraft? Pilots entering or taking-off from any airdrome should be required to adhere rigidly to the rules and regulations. "Stunt" flying should be forbidden, even at the risk of making flying as devoid of thrills as riding on a freight train. Many lives have been sacrificed for the sake of a thrill. Provisions should be made for the adjustment of claims for injury or damages to persons or property resulting from the operation of aircraft, whether licensed or not, and these provisions should be so strict in covering the determination of responsibility for accidents that aerial transportation companies or other agencies directly concerned would not hesitate to assume the liabilities that might be incurred in operating commercial aircraft. England has recognized the necessity of federal legislation. No airplanes are allowed to fly over an English city except at a height which permits them to glide beyond the city limits in case of trouble. Heavy fines are imposed for "stunting."

Insurance

There is one phase of the aeronautical industry in which America leads the European nations, aircraft insurance. We have in the United States an organization known as the National Aircraft Underwriters Association which collects and publishes hazard statistics. These data form the basis on which insurance companies make out their policies. Today there are numerous insurance companies which issue policies to owners of aircraft. The premium is based on three determining factors, (*a*) the pilot's efficiency record, (*b*) the type of plane and its performance record and (*c*) the type of engine. The Underwriters Laboratories is planning to go into this matter more intensively. The examination of aircraft is to be conducted in the same manner as automobiles and electrical supplies are inspected. This will have a double advantage, for it will not only furnish the various insurance companies with further reliable data but give the builder some assurance that the purchaser can get insurance on his airplane. Few business men care to sink money in an enterprise that is not fully protected against accidental losses. The very fact that transportation companies in the United States can take out insurance on their planes will probably do more to put commercial aviation "on the map" than any other single development along business lines.

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In closing, I wish to cite a few statistics that were published recently regarding European air travel. Between Feb. 5 and Aug. 31, 1920, the aerial passenger and mail services of Germany have made 5378 flights, negotiating over 533,000 miles with the loss of one pilot. The public air transport over French territory, and operated by French companies abroad, flew over 700,400 miles in the past year, with but one fatality. From May, 1919, to Dec. 1, 1920, the London-Paris and London-Brussels services have made several trips daily and have had only one passenger killed. From May 17 to Sept. 30, 1920, the London-Amsterdam mail and passenger services flew 93,-200 miles with no accidents of any kind. The aerial passenger, mail and express services of England have, from May, 1919, to July, 1920, a period of 15 months, flown over 1,500,000 miles or 60 times the distance around the world.

RECENT PROGRESS IN MILITARY AVIATION

By Major H S Martin[1] U S A

The author outlines recent progress by the Engineering Division in the diversified problem of the development of all heavier-than-air equipment, including the 15 types of airplane at present believed necessary to fill Army-Air-Service requirements. The subject is discussed under the headings of the airplane proper, the powerplant, the armament and the equipment, inclusive of illustrations.

The development of existing engines, especially the Liberty 12-cylinder type and the Wright 180 and 300-hp. units, is outlined and engine tests conducted with a view to improving engine performance are commented upon. The problems of armament development are stated and the work of equipment development is reported as having been confined largely to crash and leakproof tanks, parachutes, hangars, take-off mats and cameras. Work has been done also on navigation instruments and the use of radio for navigation.

With the time available it is possible to give only a brief outline of my subject, and much of importance will be neglected. I will endeavor to give in a few words an idea of recent progress by the Engineering Division with its diversified problem of the develop-

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ment of all heavier-than-air equipment for the Army Air Service. Briefly stated this problem includes the development of the 15 types of airplanes, embracing those for pursuit, attack, observation, bombing and training, at present believed necessary to fill Air-Service requirements. When we consider that a military airplane carries from 1000 to 20,000 lb. of crew with oxygen, parachutes, other conveniences or necessities, fuel and oil, machine-guns, cannon, ammunition, sights and instruments of various kinds, bombs, photographic and radio equipment, a total distance of 300 to 1000 miles or more, and at a speed of from 100 to 180 or 190 m.p.h., and that the engine, all armament and equipment must operate or be operated satisfactorily at air temperatures varying from 100 deg. above to 50 deg. below zero, fahr., and in all weather conditions, the diversity of the problems encountered will be appreciated.

It is usually most convenient in a discussion to consider the complete airplane under the heading of the airplane proper, the powerplant, the armament and the equipment. The airplane proper is perhaps the least of our troubles. We are able to build airplanes strong enough, and thanks largely to the engines available we are rarely obliged to discard an experimental airplane because of poor performance. This, of course, does not mean that performances cannot be considerably improved. However, the installation of all that goes into an airplane is rarely accomplished to our complete satisfaction. It is a very difficult job and remains to be done in making satisfactory installations of engine, armament and equipment. The Fokker D VII with the Packard engine is an engine installation that provides sufficient strength and rigidity, and at the same time the engine is accessible, which means much to those responsible for keeping airplanes in commission. It is a neat installation that is not compatible with simplicity. The Verville Packard Racer shows a leaning toward the other extreme. This is not a strictly fair comparison since this airplane was not originally designed for the engine.

Going to one or two of the types at present considered to fill Air-Service requirements, we have the Thomas Morse MB-3, a single-seater pursuit airplane with the 300-hp. Wright engine. Some of these airplanes will soon be in service on the Border. The G. L. Martin Co. MB-2, shown in Fig. 1, is a short-distance night-bombing airplane with two Liberty 12-cylinder engines. This airplane is a

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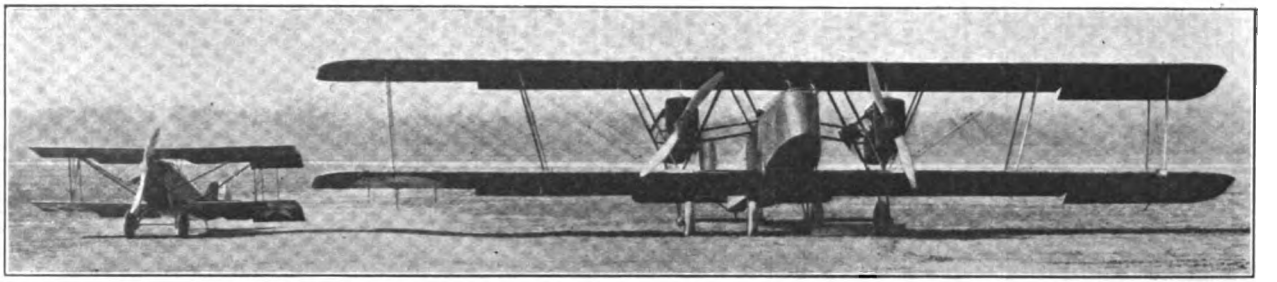

FIG. 1—THE VERVILLE MESSENGER AND THE MARTIN NIGHT-BOMBING AIRPLANES

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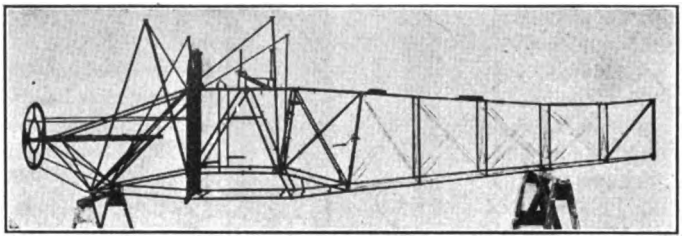

FIG. 2—THE STEEL-TUBING FRAMEWORK FOR THE FUSELAGE OF A NIGHT-PURSUIT AIRPLANE

development of the Martin bombing airplane originally delivered to the Air Service in 1918. The small airplane shown in front of the Martin bombing airplane is the Verville Messenger. This airplane was built by the Lawrence Sperry Aircraft Co. in accordance with a design furnished by the Engineering Division. The original idea was an airplane for messenger work, but it is possible that it may be of use for training.

For night pursuit we have a recent acquisition in the Curtiss Co.'s NP-1 airplane with the Liberty six-cylinder engine. This airplane is still experimental, having just completed its static test. The construction of the fuselage is of steel tubing as is illustrated in Fig. 2.

Perhaps the best method of laying out a new design is that requiring a mockup which is a model true to size of an airplane with the engine and all armament and equipment installed. In this way the clearances, location of armament and equipment and engine installation can be studied and corrected far better than by drawings.

DEVELOPMENT OF ENGINES

Going to the question of engine development, our first task has been to develop existing engines, especially the Liberty 12-cylinder type and Wright 180 and 300-hp. units. The Liberty engine has been fitted with inverted carbureters which have improved the operation and are at the same time much more accessible for adjustment. The altitude control has been improved and made effective at higher altitudes. The Wright 300-hp. engine has been fitted with inclined magneto brackets, making a simpler engine-bed possible and eliminating the necessity for right and left-hand magnetos.

Very many engine tests have been conducted with a view to improving engine performance. With anti-knock fuel and high-compression pistons consumptions lower

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than 0.45 lb. per b.hp-hr., in one case 0.42 lb., have been observed. This places aviation engines on a footing with the best Diesel engines as regards fuel-consumption per delivered horsepower-hour. A large number of single-cylinder tests have been made of air and water-cooled engines under construction or being considered for production. One test of a 5½ x 6½-in. water-cooled cylinder with four spark-plugs showed an increase in power, but the gain in using more than two plugs is probably not worth the added complication. The General Electric supercharger for the Liberty engine, with the variable-pitch propeller, is being given flight tests. Steps have been taken to develop a supercharger for the Wright 300-hp. engine. We also propose letting a contract for a gear-driven supercharger.

Our work in the development of new types has been largely concentrated on large water-cooled engines and air-cooled radial engines of from 60 to 350 hp. The 700-hp. Model W engine designed by the Engineering Division, which is now starting its first run, is shown in Fig. 3. A reduction-gear for the engine has been designed and will be constructed.

The preliminary design of a 1000-hp. 18-cylinder engine is completed and work is progressing on the complete design. The Packard series, an eight-cylinder for training, a small 12 for pursuit airplanes and a large 12 for bombardment types, have completed their tests. The large 12 is the engine installed in the Verville Packard Racer. Additional small orders have been placed for

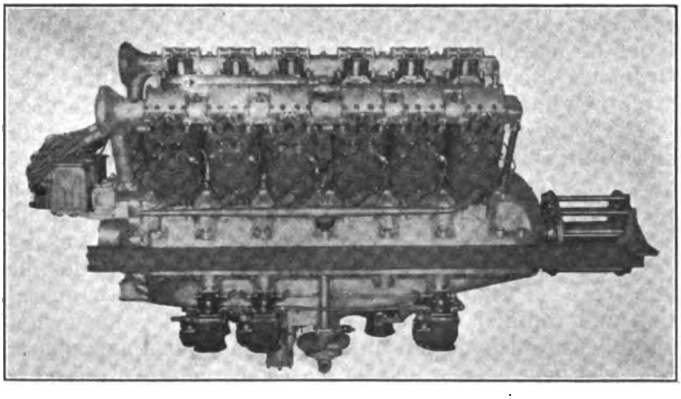

FIG. 3—THE TYPE W 700-HP. ENGINE WHICH HAS BEEN DEVELOPED BY THE ENGINEERING DIVISION OF THE AIR SERVICE

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these engines with modifications. It is proposed to increase somewhat the size and horsepower of the small 12-cylinder unit. The Wright cannon engine is being modified as a result of its tests and we hope to have soon a satisfactory engine for the 37-mm. cannon that is shown mounted in an airplane in Fig. 4.

The radial air-cooled types are being covered by the Lawrence 140 to 160-hp. for training airplanes, and the 350-hp. Weinberg and the Wright engines for service types. The Wright engine has started running, the Weinberg is being prepared for its preliminary tests and we hope to have the Lawrence soon.

For a radial water-cooled engine we have under consideration one of the barrel type known as the Almen engine. This engine will permit a cannon to be fired through the crankshaft, and in addition an engine of this type of 350-hp. would have a diameter of about 18 in. and a length of about 36 in. This feature of compactness is of course a great advantage. While the general idea is not new, it is believed the present model offers a chance of success, and its advantages justify the expenditure of some time and money.

Problems of Armament Development

Passing to armament development, the main problems are to mount the fixed and flexible machine-guns and cannon of varying calibres so as to provide for the satisfactory feeding of the ammunition and the ejection of the empty shells, to provide for the synchronization of the fixed guns and to provide for carrying bombs. We endeavor to provide for interchangeability of the various types of machine-gun. It should be explained that the Ordnance Department of the Army manufactures the machine-guns, cannon and bombs used by the Air Service.

The location of fixed guns has been confined to rather narrow limits because they are synchronized by a device driven by the engine, usually by mechanical means. With the development of the electrical synchronizer the problem will be greatly simplified, since wires are more easily located than tubes, rods or cables. In mounting flexible guns three of the requisites are field of fire, ease in operation and rapidity of fire. The field of fire is somewhat dependent on the design of the airplane, but a new mount has been developed which increases the field of fire and is reasonably easy to operate. To assist the observer or gunner in handling the guns, a wind compensator for the

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flexible mount has been designed and constructed. The force required to move two guns as well as oneself against a wind blast of from 125 to 150 m.p.h. would ordinarily be underestimated, and the compensator is designed to assist the operator by means of springs.

For securing volume of fire, a mount to carry four Lewis guns has been constructed. To take advantage of the rapidity of fire of the Browning it has been mounted flexibly. This has necessitated designing a reel for the

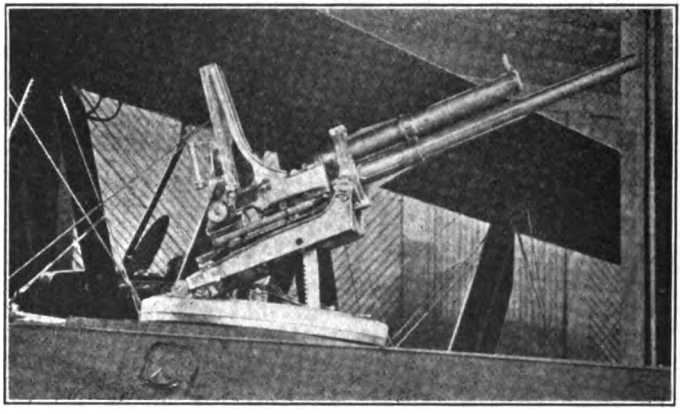

FIG. 4—THE 37-MM. CANNON MOUNTED IN AN AIRPLANE

ammunition similar in purpose to the Lewis gun magazine. The 37-mm. cannon has been mounted in almost every conceivable position in the airplane where it would be of any use. The 2.95 mountain gun has been mounted and fired from the Martin bombing machine.

EQUIPMENT DEVELOPMENT

Equipment development has been confined largely to crash and leakproof tanks, parachutes, hangars, take-off mats and cameras. Work has been done on navigation instruments and the use of radio for navigation. One instrument deserving mention is the universal gasoline gage which will go in any tank from 10 to 50 in. in diameter, and also permits some choice in the location of the dial.

Crashproof is a term applied to tanks designed to prevent gasoline spilling all over the engine, with fire resulting, in a crash which often splits the tank. The tanks are of the usual construction except that they are

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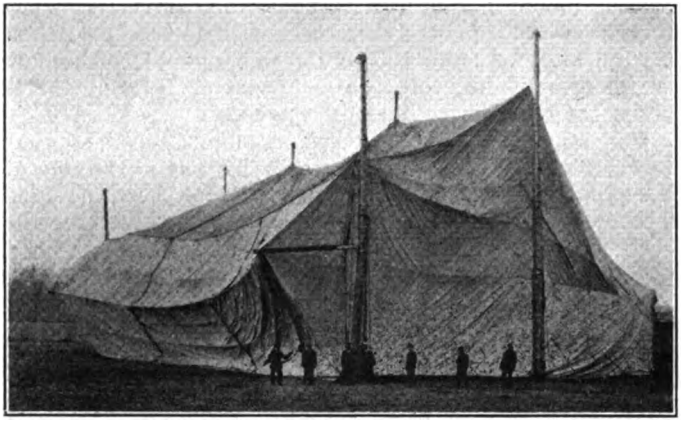

FIG. 5—A LARGE CANVAS HANGAR CAPABLE OF HOUSING THREE MARTIN BOMBING AIRPLANES

covered with a thin bag of live rubber. Experiments show that this is an advantage.

The development of leakproof tanks is being continued but the advances in the armament of airplanes with heavier calibers and more destructive ammunition will apparently require a new and different solution before long.

Satisfactory parachutes of the back, seat and lap type have been developed, and some are in use. The back type will probably be used for training, while the seat and lap types will be used for service. The latter types are somewhat smaller and better suited for service because of this, and also because they interfere less with the operations of the pilot, observers and others. In an attempt to get the parachute entirely out of the airplane, and yet avoid the disadvantages of the type attached to the airplane, we recently experimented with what is termed the detachable parachute fuselage. The parachute is carried in the rear of the fuselage and in case of accident the pilot pulls a lever disconnecting himself and the rear of the fuselage.

The technical development of radio is under the direction of the Signal Corps of the Army, the Air Service making service tests only. One phase of these tests is an automobile equipped with radio with which it is possible to keep in communication with an airplane, while the automobile is running along the road.

The development of hangars is a difficult problem. The

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effort to make them easy to erect, take down and transport, and yet withstand all weather conditions results in something of a compromise. One recently constructed by the Henrix Leubert Co. which is perhaps the largest canvas hangar yet constructed and will house three Martin bombing machines, is shown in Fig. 5.

To enable airplanes to take-off in muddy fields we are developing so-called take-off mats. Although it might appear a relatively simple matter, it is very difficult to provide 300 or 400 ft. of a satisfactory width to stand up under rough treatment, and yet not require too much in the way of trucks to transport it. At present there are two types, one a rope net with canvas, the other a canvas mat with hickory slats.

FUEL PROBLEM IN RELATION TO ENGINEERING VIEWPOINT

By A L Nelson[1]

The author states preliminarily that it is believed that never before in the history of the Society of Automotive Engineers has a single problem been so universally studied as the fuel problem that is confronting the industry today. It is also believed that never before has the industry had a problem which includes such a wide scope of work. The solution calls for the service of every class of engineer, inventor and scientist.

The paper does not attempt to give highly scientific information; its real purpose is to appeal for a broader viewpoint and to give illustrations and tests which show that the solution of a problem may lie in an entirely different method than that which often becomes stereotyped by sheer usage, rather than by its specific merit. In the solution of the fuel problem we undoubtedly will have to change some of our old habits, replacing them by studiously worked out viewpoints. The further object of the paper is to seek the correlation of the experience of the entire engineering fraternity, to obtain the comments of its members and receive any suggestions they may offer.

After giving recognition to the cooperation and assistance already received and making general comments upon the desirability of radical changes in viewpoint, the author enters upon a discussion of the engine power required to drive a car at constant speed and the effect

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of using higher piston compression-ratios, illustrated by a table and chart, with a view to demonstrating the value of modified viewpoint. In like manner he discusses the constant-clearance aluminum piston and the fuel vaporizer. The basic principles of the engine used in testing are next considered and copiously illustrated, together with the apparatus used in the dynamometer and practical driving tests that were made. Charts show the percentage comparison of results and these are explained.

After a discussion of ideal economy, it is stated that the tests show that an absurd waste is rampant in the present method of applying the indicated engine power and that this subject should be studied from every angle. A close study from the brake-horsepower standpoint may justify changing both transmission and rear-axle drive ratios. The latter combinations, together with engine developments, look the most promising at present. The progress we make will be measured by the extent to which we expand our engineering viewpoint.

It is believed that never before in the history of the Society of Automotive Engineers has a single problem been so universally studied as the fuel problem which is confronting us today. It also is believed that never before have we had a problem which includes such a wide scope of work. The solution calls for the service of every class of engineer, inventor and scientist. It is most gratifying to realize the large amount of ingenious research that is giving us day by day a broader view of the problem. When we have worked out the proper viewpoint and thoroughly understand our problem, the eventual solution should follow with relative ease. It is on this ground that particular emphasis is laid on the engineering viewpoint, for, obviously, this will have a large bearing on keeping our efforts going in the right direction.

This paper does not attempt to give highly scientific information, the correlation of the last word in test data or to claim the solution of even the merest detail of the fuel problem; its real object is to appeal for a broader viewpoint and give a few illustrations and tests which show that the solution of a problem may lie in an entirely different method than that which often becomes stereotyped by sheer usage, rather than by its specific merit. The American engineer is too ingenious, too susceptible to practical new viewpoints to follow an old beaten path in only one direction, unless it follows from being off-guard and letting it become a habit. In the solution of

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the fuel problem we undoubtedly will have to change some of our old habits, replacing them by studiously worked out viewpoints. The illustrations given will clarify what is meant and will, together with the tests, serve to give a quantitative analysis of the merits of the results obtained by the changes in viewpoint. The further object of this paper is to seek the correlation of the experience of the entire engineering fraternity, to obtain their comments and seek their suggestions. It is hoped that the discussion following the reading of this paper will bring out much valuable information and materially expand our viewpoint of the fuel problem.

Recognition of Cooperation and Assistance

The eventual solution of the fuel problem will likely be the correlation of the proper solution of the almost innumerable details. We cannot, therefore, help but applaud the successful efforts of men whose work has earned our highest esteem, nor can we help but applaud those that are succeeding to a lesser degree. That this paper might be of interest to as large a number as possible a preliminary paper was submitted to representative engineers asking for suggestions, criticism and any comments which would help make the final paper a cooperative one. The generous response was very helpful indeed. The sincerest thanks and the assurance that the help is highly appreciated are extended. Many of the suggestions offered are indeed worthy of separate papers and, therefore, it is impossible to incorporate them in this. As a case in point, the importance of turbulence will not be mentioned, but it is hoped that the discussion following the reading of this paper will cover the matter as fully as possible.

As a matter of an expression of gratitude to those whose help has been most liberal the following names are mentioned. I am particularly indebted to C. S. Crawford, Harold Nutt, J. G. Vincent, H. L. Horning, H. M. Crane, C. F. Kettering, C. F. Johnson, E. A. De Waters, C. R. Richards, C. P. Grimes, Thomas Midgley, Jr., Frank Johnson and others; also to the members of the engineering department of the Premier Motor Corporation for their assistance in the preparation of the paper.

Some remarks will be made later which it is hoped will not be misconstrued. They refer to faults in regard to which the most exacting engineers cannot be justly accused and will not apply to them. However, if we are

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to be frank with ourselves, the remarks will apply to all of us to at least a small degree without being looked upon as non-constructive criticism. However well the specialist may know his particular subject, if he is presented with an entirely different viewpoint of some specific problem, the aspect of the problem may be entirely changed. This may lead to an easier solution than that obtained without the change in viewpoint. We are all familiar with the cleverness with which the scientists have worked into the very heart of natural science.

For instance, in mathematics, there are clever tricks making possible the easy solution of certain types of differential equation. These are nothing more or less than simple inventions but the progress of mathematics would have been delayed had they not been discovered. It is thought that discoveries of analogous schemes will have a large bearing on the eventual solution of the fuel problem. When we compare the present state of our problem with the highly developed state of the natural sciences, it is thought that all of us will willingly open our minds fully to the possibilities of changes in viewpoint.

Let us consider how we often discuss some of our problems affecting the fuel situation, without the important specific correlation of engine and chassis data. We know off-hand the general engine characteristics at full, three-quarter, one-half, and one-quarter load. We know the power, friction losses, economy and the like. This is all very proper and applies very well to what the engine *can do*, but how about the more important questions of engine characteristics while working at loads that it is *called upon to do* in the car? How much specific information can we give off-hand on these more important engine characteristics so vital to the solution of the fuel problem?

We know the general bearing in a vague way that the chassis weight, rear-axle gear-ratios, engine size, piston compression-ratios and similar factors have on the fuel economy. The more complicated cases of rapidly changing driving conditions are little understood in a specific way. Are we not even weak on the conditions obtaining at constant-speed driving, apparently for no other reason than our *habit* of neglecting to investigate this important matter? This investigation can be made readily after determining the power required to drive the car at constant speeds.

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Engine Power Required to Drive the Car at Constant Speed

In relation to car speed, Fig. 1 shows the engine brake horsepower required to drive one of our American cars of the large-car class. The figure also shows the brake horsepower available and the percentage of the available power used at each speed. Table 1 gives the data relative to car weight, tires and course. It also gives the brake horsepower required for car speeds from 10 to 60 m.p.h.,

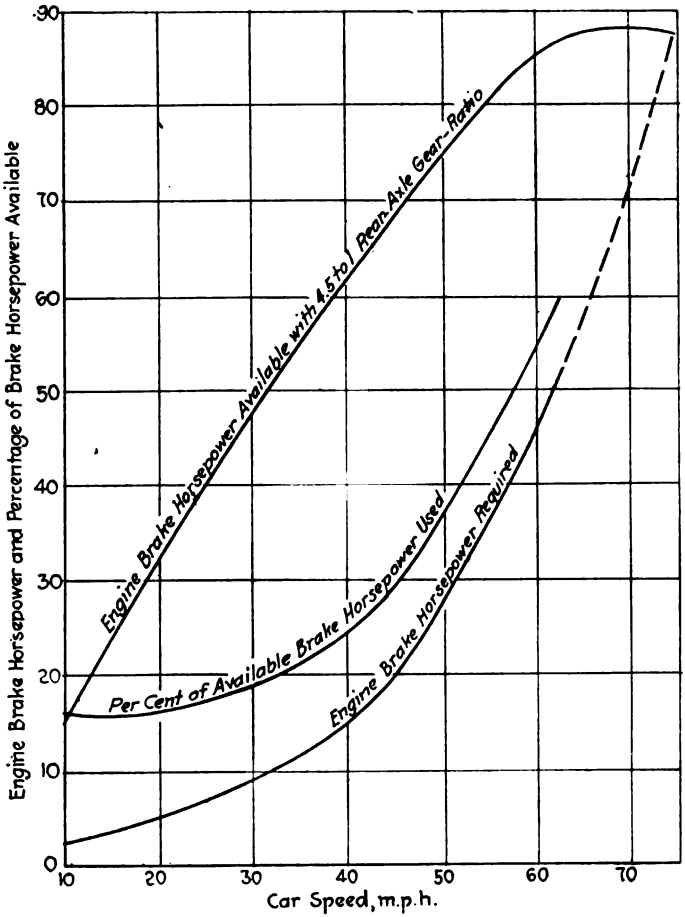

Fig. 1—Engine Power Required at Constant Car Speed

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TABLE I—CAR CHARACTERISTICS FOR CONSTANT SPEED

Car Speed, m.p.h.	Power Required of Engine, b. hp.	Rear-Axle Gear-Ratio						Constant To Be Multiplied by the Ounces of Gasoline Consumed in 2 Min. To Get the Fuel Consumption in Pounds per Brake Horsepower per Hour	Constant To Be Divided by the Ounces of Gasoline Consumed in 2 Min. To Get the Miles per Gallon[2]
		4.5 to 1		3.5 to 1		2.5 to 1			
		Engine Speed, r.p.m.	Engine Pull at 15.756-In. Arm, lb.	Engine Speed, r.p.m.	Engine Pull at 15.756-In. Arm, lb.	Engine Speed, r.p.m.	Engine Pull at 15.756-In. Arm, lb.		
10	2.40	450	21.3	350	27.4	250	38.4	0.7820	32.27
15	3.75	675	22.2	525	28.6	375	40.0	0.5000	48.40
20	5.20	900	23.1	700	29.7	500	41.6	0.3610	64.53
25	7.00	1,125	24.9	875	32.0	625	44.8	0.2680	80.67
30	9.10	1,350	27.0	1,050	34.7	750	48.5	0.2060	96.80
35	11.50	1,575	29.2	1,225	37.6	875	52.6	0.1630	112.90
40	15.10	1,800	33.6	1,400	43.1	1,000	60.4	0.1240	129.10
45	20.10	2,025	39.7	1,575	51.0	1,125	71.5	0.0933	145.20
50	27.60	2,250	49.1	1,750	63.1	1,250	88.4	0.0680	161.30
55	36.50	2,475	59.0	1,925	75.9	1,375	106.2	0.0514	177.50
60	46.20	2,700	68.5	2,100	88.0	1,500	123.2	0.0406	193.60

[2]The weight of 1 gal. of gasoline is taken as 96.8 oz.

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DATA RELATING TO TABLE

Outdoor Temperature (average) deg. fahr.	76
Barometer (average) in. of mercury	30.15
Weight of Car with Fuel and Two Spare Tires, lb.	4,340
Weight of Driver, lb.	180
Total Weight of Car and Driver, lb.	4,520
Tires	Firestone Cord
Size of Tires, in.	33 x 5
Air Pressure, Rear Tires, lb. per sq. in.	50
Air Pressure, Front Tires, lb. per sq. in.	45
Course	Indianapolis Speedway
Pavement	Brick
Length of Course, miles	½
Direction of Driving	North and South
Roll of Right Rear Wheels per Turn, in.	106.25
Roll of Left Rear Wheels per Turn, in.	105.00
Average Roll of Rear Wheels per Turn, in.	105.62
Number of Turns per Mile	600
Exhaust Cutout	Open
Oil	Mobiloil B

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together with the engine speed and torque for rear-axle gear-ratios of 4.5 to 1, 3.5 to 1 and 2.5 to 1. The constants given in the last two columns are used when running engine tests on the dynamometer to compute the gasoline consumption in terms of pounds per brake horsepower per hour and miles per gallon.

The method of obtaining these data is to drive the car on a given course at constant car speeds corresponding with a fixed carbureter throttle setting, then to remove the engine from the car to the dynamometer stand to determine the power at those settings and the engine speed corresponding to the car speeds. It is necessary to duplicate very accurately the fixed throttle settings when the engine is put on the dynamometer; therefore, a micrometer adjusting screw was attached to the carbureter throttle-shaft mechanism, always using full turns only and then measuring from the locking nut to a fixed line on the screw as a means of recording the setting. The speed of the car was obtained by timing with a stop-watch on a ½-mile measured course, driving in both directions for each setting to eliminate the wind resistance by taking the average speed. The engine speed is obtained by noting the roll of the rear tires per turn and with the car speed and rear-axle gear-ratio, the number of revolutions per minute is calculated.

The average result of the dynamometer tests is plotted and the results of the smooth curve drawn through these points are given in Table 1. Several important details, such as cooling-water temperatures, oil temperatures, air pressure under the engine hood, and the like, need not be given here. However, it is suggested for accurate work that, in addition to the use of fixed throttle settings, manometer readings be taken of the intake-manifold depression together with the air temperature. The method of keeping the water circulation the same on the dynamometer as in the car will be given in describing the equipment used in the engine tests to follow. Referring again to Fig. 1, note that the usual engine characteristics of even one-quarter load do not apply below 40 m.p.h. At average driving speed the engine is only working at 16 to 19 per cent of full load.

By means of the data given in Table 1, which states the standardized power requirements of this particular model of car, we can analyze readily the engine char

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acteristics by running tests on the dynamometer. It is obvious to expect that poor economy is caused by misapplication of the engine rather than poor engine economy. The analysis should give us relative values on which to consider the feasibility of using two-speed rear-axles, more speeds in the transmission, or perhaps an entirely new and better way will be devised eventually to keep the load factor of the engine high to obtain better economy. Tests will be given further on giving quantitative analysis of the conditions existing.

The conditions revealed by the correlation of engine and car characteristics are so bad that both the public and engineers need a decided change in viewpoint; the public in what they demand, and the engineer in what to furnish and in what to educate the public to expect. Some illustrations will be given next to demonstrate results following from a change in engineering viewpoint.

Higher Piston Compression-Ratios

As an illustration of remodeling our viewpoint, let us consider the effect of using higher piston compression-ratios. We all know that the compression-ratios, as used in aviation engines, give us much higher fuel economy than those used ordinarily in automobile engines. Then why not use high compression-ratios for automobile engines? We are told that higher compressions make the engine knock badly. Experience tells us that the simplest way generally accepted for getting rid of the

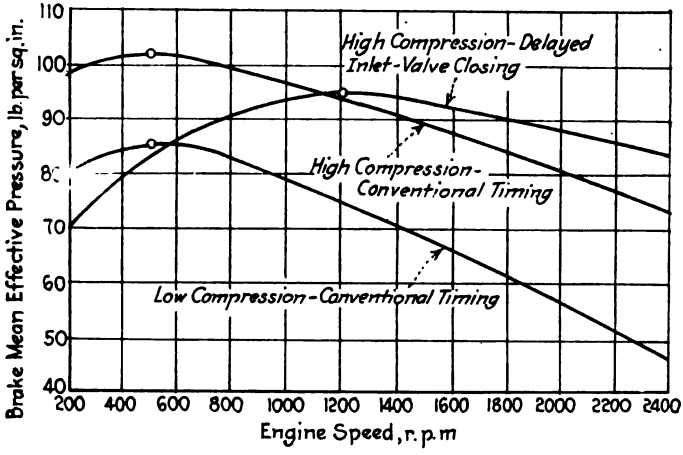

Fig. 2—Comparison of General Brake Mean Effective Pressure Curves

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knocking is to lower the compression-ratio. The point is, shall we accept this way as final? Why not try to accomplish the same result some other way and at the same time maintain the higher economy?

We all know that an engine at full load may knock badly at 500 r.p.m. and that perhaps it will not knock at all at 1200 r.p.m. If we study the curve of brake mean effective pressure, we will find that, at 500 r.p.m., the brake mean effective pressure is greater than at 1200 r.p.m. The "high compression-conventional timing" curve in Fig. 2 illustrates this. By lowering the compression to eliminate the knock, we obtain the lowest curve. Suppose we go back to the higher piston compression-ratio and at the same time we delay the inlet-valve timing. Experiments show that we get a brake mean effective pressure similar to the curve so marked, the peak of the curve coming at a higher speed than that given by the conventional timing. The pressures at the lower speeds are reduced, which is the desired result to overcome the knocking, while the pressures at the higher speeds are materially increased.

The exact timing to use depends on the valve sizes, intake passages, carbureter characteristics and similar factors. The results obtained are more far-reaching than merely keeping the pressures within a range to eliminate the knocking at the lower speeds, and increasing the power at higher speeds. The most desirable results are obtained under car-driving conditions. The small charge of mixture required is taken into the cylinder and compressed to a smaller volume than in the case of the lower compression; also the charge is purer, due to the better scavenging of the higher-compression pistons. The comparative tests given further on for 5 to 1 and 4.25 to 1 compression pistons at full load show increases of 13 and 24 per cent in the brake thermal efficiencies at 700 and 2100 r.p.m. respectively; while at these same speeds and at loads required by the car the increases are 22 and 41 per cent respectively. (See Figs. 29 and 30, at 20 and 60 m.p.h. respectively.) These results are representative of only the first attempt, yet they are quite appreciable gains in economy and are due solely to the change in viewpoint on compression-ratios.

Constant-Clearance Aluminum Piston

Suppose we consider the aluminum piston, which is almost universally used in aviation engines. The high thermal conductivity of aluminum allows the heat to

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flow from the pistons more freely than from any other metal commonly used, contributing highly to the best known results obtained from high-speed internal-combustion engines. Why are the aluminum pistons for automobiles, though largely used, condemned by some of our leading designers of national reputation? They know the sterling qualities of the aluminum aviation pistons that make the high power and economy of aviation engines possible, yet for their automobile engines they use cast iron which perhaps could not possibly be used in the aviation engines with the high compression ratios. They tell us the trouble is that the aluminum pistons expand so much when heated that they require excessive cylinder clearance and that this allows them to slap at the lower speeds, or, if fitted closer, to stick at the higher speeds. As an alternative they select cast-iron pistons with lower compression and lower economy and greater torsional vibration of the crankshaft due to the heavier reciprocating parts and occasionally scoring the cylinder blocks. Some engineers feel, in addition, that the hotter cast-iron piston helps to vaporize the liquid fuel that comes in contact with the head of the piston.

The specific heat of aluminum is greater than that of iron, but the density of iron compared with that of aluminum gives us a heat capacity per unit volume of aluminum which is 68 per cent that of iron. This is 32 per cent in favor of the iron. However, the conductivity of aluminum is 2.85 times that of iron. From these figures it will be seen that even if the iron piston was 1½ times as hot as the aluminum piston, the heat flow to the liquid fuel in contact with the aluminum piston-head would be about 30 per cent greater, and for same temperatures the heat flow would be about 94 per cent in favor of the aluminum. Since the aluminum piston-head usually is made thicker than that of cast iron, the amount of heat available would be approximately the same in both cases. From the foregoing it appears that the two pistons are on a par, except that heat flow is greatly in favor of the aluminum piston. The thing that seems to keep these engineers from changing their viewpoint is that it has become a habit to think that aluminum pistons must expand. Why not design an aluminum piston that cannot expand so far as cylinder clearance is concerned? This viewpoint changed the complexion of the whole problem and led to the development of aluminum automobile piston design that gives results thought to be in

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advance of the combined merits of the aviation piston and the cast-iron piston.

This piston is illustrated in Fig. 3. In this design the adjustable *steel* strut controls the cylinder clearance in the direction which prevents piston slap. It will be noted that the *aluminum* has nothing to do with the cylinder clearance. The strut is subject to almost the same temperature range as the cylinder; hence, the clearance remains constant through the range from a stone-cold to a steaming-hot engine. This type of piston proved very successful from the outset. It is the only type of piston, regardless of material or design, that we have not been able to make stick under abnormal conditions. It has absolutely no slapping tendencies even for a stone-cold engine. Maximum speed can be maintained on the Speedway indefinitely without causing the pistons to stick. For a more severe test the pistons were run at full load for 30 min. at 3000 r.p.m., with the radiator cooling water shut off so that the engine steamed continuously during the run (See Fig. 17). This run was made at the end of a full day of high-speed testing with no provision for cooling the oil. The cylinder clearances of the pistons were less than those of any cast-iron pistons that we know are used in quantity production. Two of the pistons had cylinder clearances of 0.0015 in., based on the

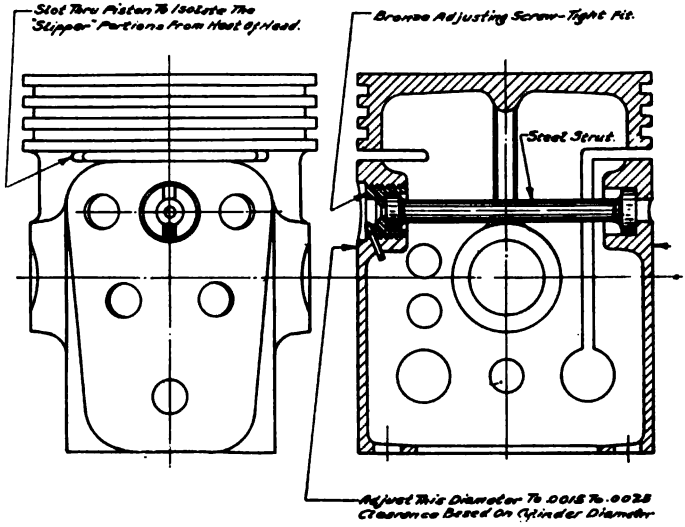

FIG. 3—A CONSTANT-CLEARANCE ALUMINUM PISTON

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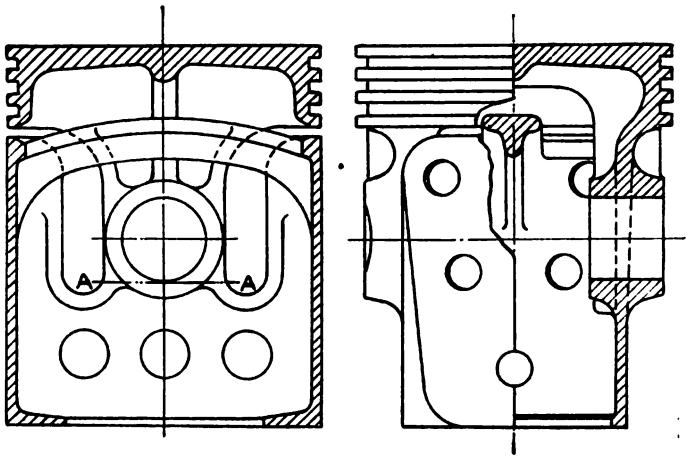

FIG. 4—ANOTHER TYPE OF CONSTANT-CLEARANCE PISTON WHICH HAS A STEEL STRUT CAST INTEGRAL WITH THE SLIPPER PORTION

diameter. The other four pistons had clearances from 0.0020 to 0.0025 in.

In spite of all the abuse we have been able to impose on this type of piston, the pistons have always come out of the tests entirely free from any scoring marks and show a decided general tendency to polish-up smoother than the conventional aluminum piston. This undoubtedly follows from the maintenance of the proper clearance at all times, thus avoiding excessive bearing loading. Another striking characteristic of the pistons is their smoothness of operation, showing that even when the slap in the conventional piston is not audible there is a rumbling sound which becomes noticeable when compared with the operation of the constant-clearance piston. This difference is very marked at both high and low speeds. When the pistons are used with the conventional timing, the knock at full load and low speeds is very materially subdued compared to the conventional type of piston. This clearly shows that cylinder piston clearance has much to do with the degree of audibility of the knock.

Fig. 4 illustrates a design which has the strut cast integrally with the "slipper" portion of the piston, the latter being well insulated from the heat of the piston-head by being separated from it. The side-thrust of the piston-pin being carried by the cantilever action at section *AA*. An alternative of this design is a steel strut cast in place or fastened in some suitable manner.

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Fig. 5 illustrates an aluminum piston that *contracts* when heated, so far as cylinder clearance is concerned. The steel struts in this case are shown cast in place. The reason the cylinder clearance increases with the heat on the piston is that the ends of the steel struts attached to the piston-ring-groove portion of the piston-head are carried outward, drawing the "slipper" portion inward since they are attached to the opposite ends of the struts. A large variety of designs can be made embodying the strut idea to accomplish variations of cylinder clearance, adjustment and the like, as may be desired for particular cases. It is hoped that these piston illustrations will fix the idea firmly that, so far as cylinder clearance is concerned, we have nothing to fear from the highly expansive aluminum as a piston material. As for the practical merits of the constant-clearance type of piston, they must be tried to be appreciated, because the results they give are so far in advance of one's highest expectations. The results are indeed a striking illustration of what can be accomplished by a mere change in viewpoint.

Fuel Vaporizer

Consider the general experience on exhaust-heated intake-manifolds. It is generally agreed that the results are fairly good, at the expense of a loss of maximum power due to unduly heating the air. On heating the fuel by "hot-spots," the air is also heated. The experience has been so general that it has practically fixed in our minds as an irrevocable fact that using exhaust heat necessarily must unduly heat the air. To show that this is not the fact, first let some suppositions be given which can be agreed to readily.

Suppose we run all the hot exhaust gases through a jacketed intake pipe, say some 10 in. long, to get ample surface for the "hot-spot;" that is, ample surface to transmit the exhaust heat required to vaporize the fuel, which, it has been observed, goes to the walls of the intake pipe or points of lowest air velocity. Such an intake pipe works well but it also heats the air along this surface, which is of low velocity, coming into contact with the large highly heated surface with the result that the maximum power cannot be obtained. At this point, suppose the old viewpoint of necessarily heating the air be discarded. Let us corrugate the intake-pipe surface so that the air passage is say 2½ in. long, without reducing the area of the inner or outer surface.

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As a practical means, materially increase the inside diameter of the intake pipe at this point and cast circular ribs on both the inner and outside surfaces. To make this clear, Fig. 6 shows a cross-section of such an intake pipe designed for the 295.2-cu. in. six-cylinder engine used in the tests to follow. Note the relatively small amount of surface exposed to the exterior of the heating chamber, which is an important item for starting out with a cold engine, and the efficient heating of the pipe at low car speeds. The heated portion of the pipe is set at an angle above the carbureter so as to

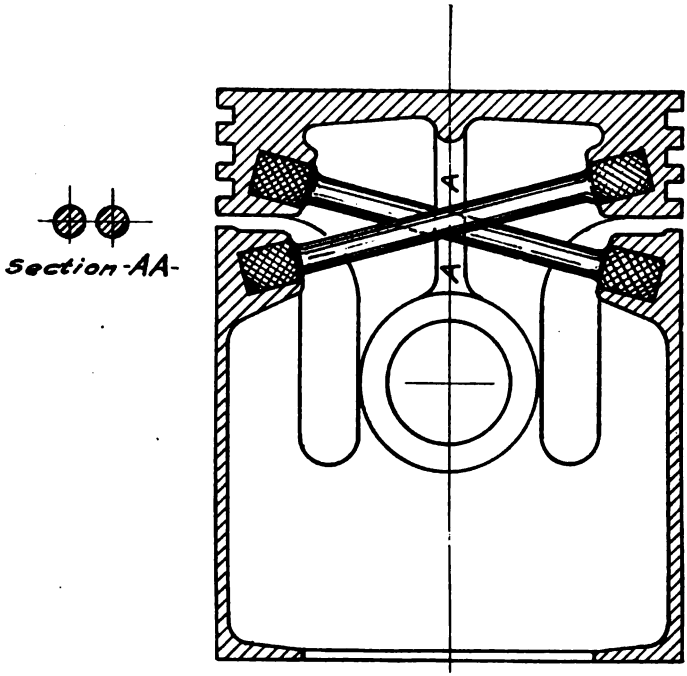

FIG. 5—A VARIABLE-CLEARANCE ALUMINUM PISTON IN WHICH THE CYLINDER CLEARANCE INCREASES AS THE PISTON BECOMES HEATED

take advantage of the inertia of the fuel globules that may be thrown directly into the large highly heated surface. This also puts a bend into the pipe to bring the flow of liquid following the wall to the inner or smaller radius of the bend. Gravity helps to get a flow of the liquid over the heated surface. It cannot get out again into the air-stream before being highly vaporized.

The liquid fuel, while in the air-stream, seeks the walls

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of the pipe, as before mentioned. The highly heated corrugated surface effectivly traps the fuel and quickly vaporizes and "super-heats" the vapor. Tests indicate that the air is very slightly heated while the fuel is highly vaporized. Kerosene is vaporized as readily as gasoline, even at speeds as low as 200 r.p.m. with wide-open throttle. The reason the air is slightly heated follows from the fact that only a very small portion of the air comes in contact with the edges of the ribs at the inner diameter. The actual length of the exhaust-heated intake-pipe is only ⅝ in. so far as the air is concerned. Tests have been run, *abnormally* heating the intake-pipe, with only a loss of 1.2 per cent of the power at 1200 r.p.m. and 2 per cent loss of power at 2400 r.p.m., compared with the best results that could be obtained from the most favorable degree of heat and unheated plain manifolds. The design as shown does not strictly confine the heat to the ribbed portion for practical reasons. If the heated portion were isolated, undoubtedly better results could be obtained so far as maximum power is concerned when using an excessive amount of heat.

The operation of the intake pipe in connection with the remainder of the intake passages to the cylinders has some peculiar characteristics that are very important. Off-hand it would appear as though the deep ribbing would offer a severe obstruction to the fuel passing to the cylinders. Let us compare what happens with that of the ordinary manifold where the fuel as a rule travels much more slowly than the air-stream flowing along the manifold walls. A considerable time interval obtains between the time the fuel leaves the carbureter nozzle and its reaching the cylinder. In the case of the intake pipe, Fig. 6, and the remaining passages to the cylinder, the heavier parts of the fuel are momentarily arrested, but they are highly vaporized quickly and pass to the cylinder at the same speed as the air-stream. Since a highly heated surface can be used without heating the air, the vapor becomes heated to a point high enough so that it does not condense while in the air-stream. Of course, the vapor going into the air-stream receives a high velocity on the outset, and the time interval for it to condense is small. Practical driving tests with and without accelerating devices verify the above explanation.

Most convincing observations are made when applying 2-in. carbureters to the engine, both on the dynamometer and on the road. For speeds below 800 r.p.m.

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with open throttle, the unheated plain intake-pipe could not be used at all. Even at higher speeds the economy was poor although the power was good, showing poor distribution. With the new-design intake-pipe the engine could be run to as low as 200 r.p.m. with wide-open throttle. However, this does not apply to 2-in. plain-tube carbureters that we have tried without making structural modifications in the design.

In connection with the exhaust heating of the special intake-pipe, it made it possible to equip the engine with a 2-in. carbureter. The car accelerates well in cold weather, without pulling the choker, by the time it can be driven out of a cold garage onto the street. A valve, manually operated, forces all the exhaust heat through the intake. This is used until the engine heats to the normal operating temperature, or it can be left on con-

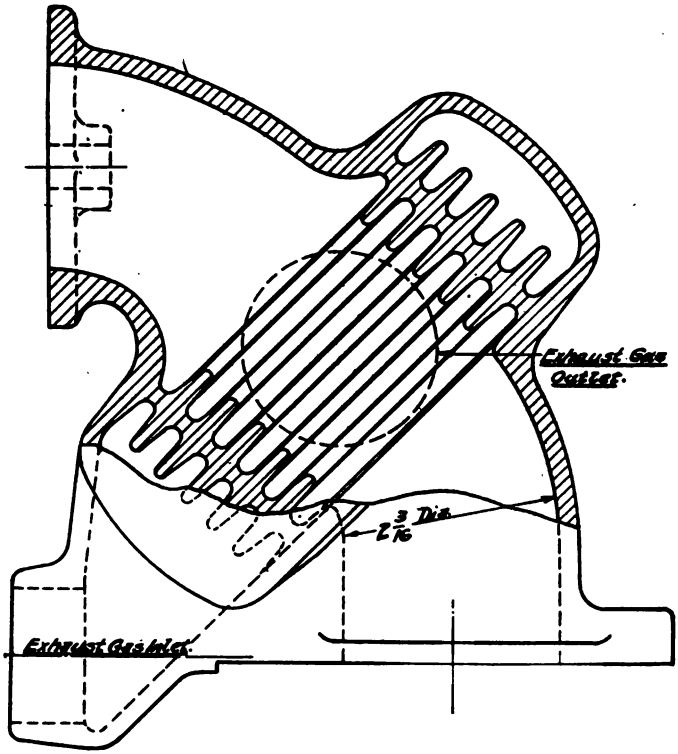

FIG. 6—CROSS-SECTION OF INTAKE-PIPE FUEL VAPORIZER USED IN THE TESTS

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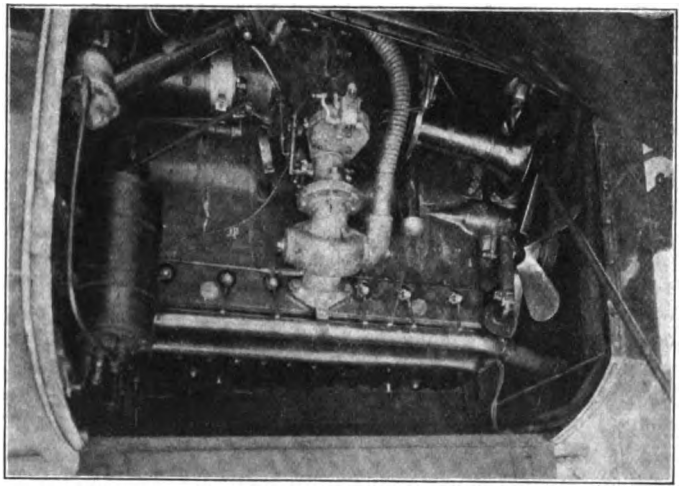

FIG. 7—THE CARBURETER SIDE OF THE ENGINE IN PLACE IN THE CAR

tinuously without causing any harm except a slight restricted exhaust passage for high speed in this particular experimental design. The good acceleration while cold indicates the "super-heating" of the fuel; in other words, it does not condense materially before reaching

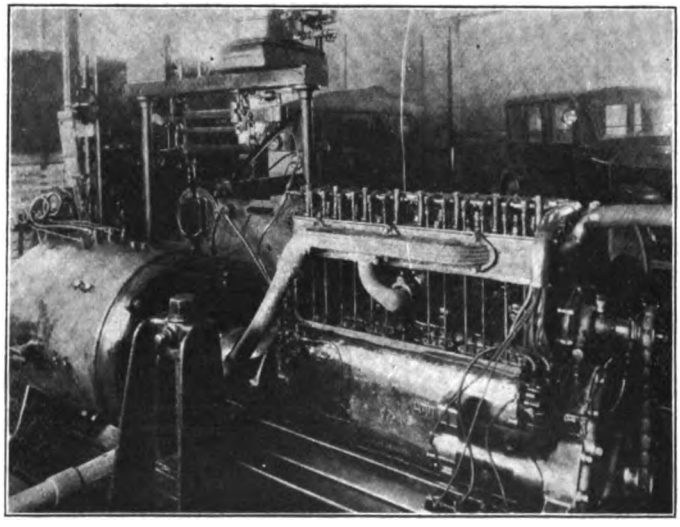

FIG. 8—THE EXHAUST SIDE OF THE ENGINE

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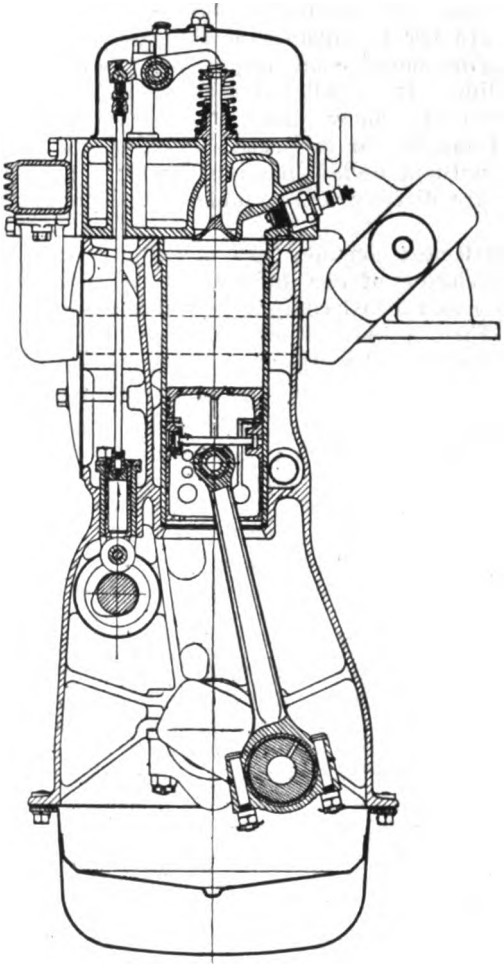

FIG. 9—CROSS-SECTION OF THE ENGINE

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the cylinders, even when the engine is cold. With the larger carbureter and its corresponding higher power at both low and high speeds, there also obtains a smoothness that never was obtained with smaller carbureters. The degree of flexibility, smoothness, economy and power are far in advance of the best previous results. The engine shows good torque, right down to the point of stalling. It is believed that even these preliminary investigations show that the conventional hot-spot method can be far surpassed and that the fuel can be heated without unduly heating the air. The results obtained are directly attributable to the change in viewpoint.

We will next consider tests showing the application of the correlation of car and engine characteristics using 4.25 to 1 and 5 to 1 compression pistons in the same engine. First a brief description of the basic principles of the engine and testing apparatus will be given.

Basic Principles of the Engine

It will be of interest to emphasize some of the high lights of the engineering principles of the engine and give data that may be helpful to those who might wish to go further into details. It is a valve-in-head, six-cylinder, 3⅜ x 5½-in. engine of 295.2-cu. in. displacement. The cylinder block and upper crankcase is a one-piece casting of aluminum alloy, with inserted cylinder sleeves of cast iron machined all over. The cylinder-head is of cast iron and detachable. Fig. 7 shows the general appearance of the engine as installed in the car. Fig. 8 shows the opposite side of the engine with the side cover-plate and valve-cover removed. Fig. 9 shows a cross-section of the engine which gives a fairly good idea of the detailed construction. The crankshaft is of the three-bearing type and of liberal dimensions. The hollow crankpins are 2¼ in. in diameter and 1¾ in. long. The shaft is drilled for oil passage at 25-lb. per sq. in. pressure to all the main and connecting-rod bearings.

Attention is called to the unique cylinder-sleeve construction with particular reference to the application of the packing at the bottom of the sleeve. The sleeve at the bottom diameter has a snug slip-fit in the aluminum case. The sleeve, however, has been shown to have a very slight axial movement here. This follows from the fact that the aluminum case is not subject to as high a temperature range as the cast-iron sleeve, the higher coefficient of expansion of the aluminum being offset by the greater temperature range of the sleeve. The

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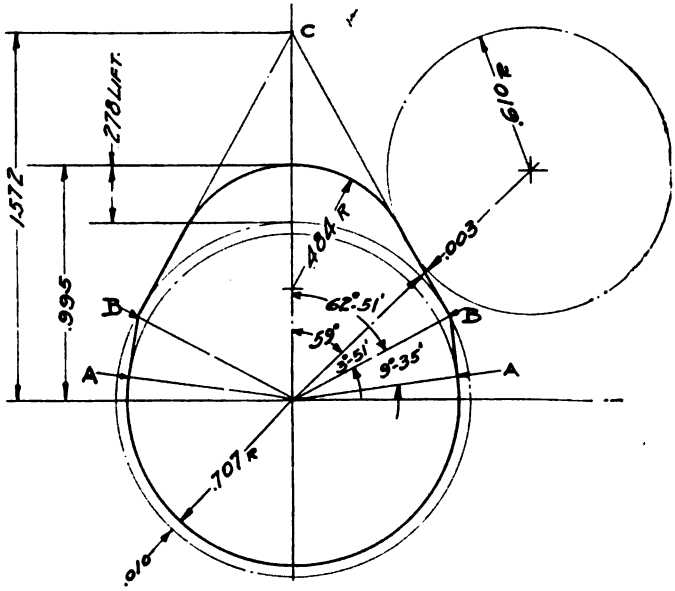

FIG. 10.—DETAILS OF THE INLET AND EXHAUST CAMS

The Exhaust Cam Leads the Inlet by 118 Deg. *AB* and *BC* Are Straight Lines Intersecting at a Sharp Angle at *B*

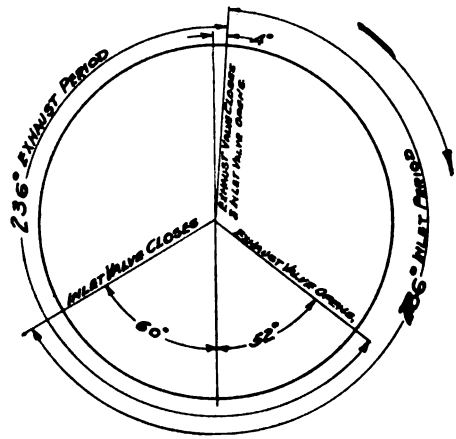

FIG. 11—FLYWHEEL TIMING DIAGRAM FOR CHECKING THE ASSEMBLY OF THE CAMSHAFT IN THE ENGINE

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pressure on the combination cork and hydroil packing is in an axial direction only; that is, there are no radial components of pressure from the reactions of the packing to throw the sleeve out of round. This is the characteristic difference from other types of sleeve constructions and is the basic principle making the installation of a sleeve construction successful.

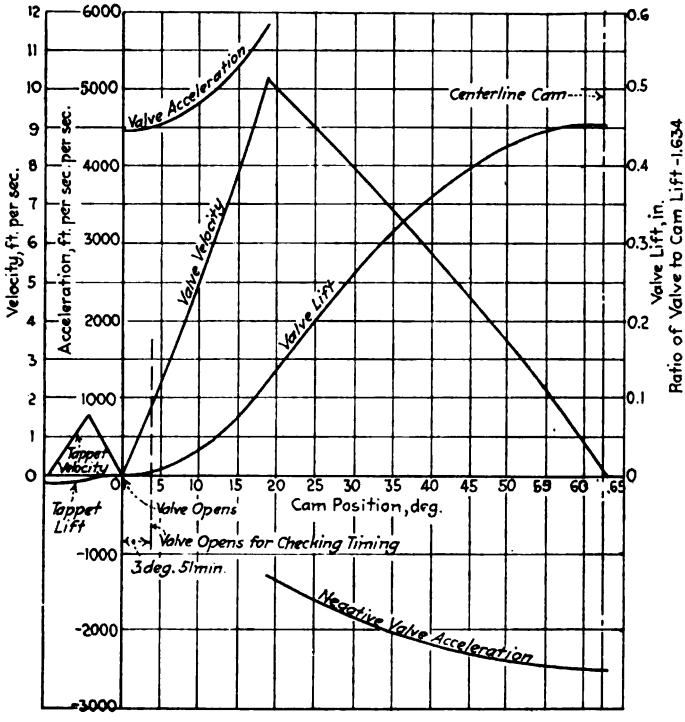

FIG. 12—VALVE-MECHANISM CHARACTERISTIC CURVES AT AN ENGINE SPEED OF 3000 R.P.M.

Fig. 10 gives the details of the inlet and exhaust cams, both cams being identical. Fig. 11 gives the flywheel timing diagram for a valve-stem end-clearance of 0.0212 in.; however, the operating valve-stem clearance is 0.015 to 0.017 in. This is a special type of cam having a zero opening and closing valve velocity regardless of engine speed. A detailed description and mathematical analysis of this type of cam will be found in the 1917 S. A. E. TRANSACTIONS, Part 1, pages 328 to 337. Fig. 12 gives

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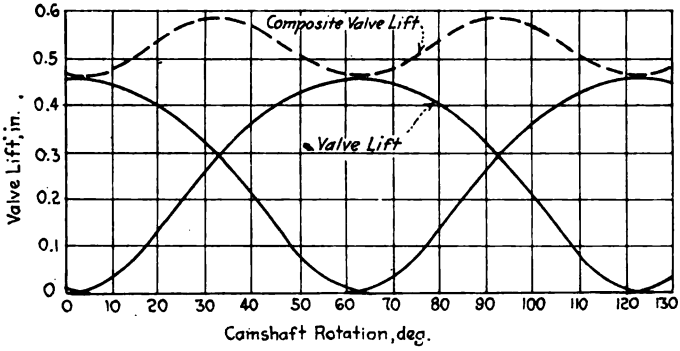

FIG. 13—THE INLET-VALVE TIMING OVERLAP

the valve-mechanism characteristic curves for an engine speed of 3000 r.p.m. Attention is called to the design to obtain a high acceleration away from the cam and a low acceleration toward the cam; that is, the acceleration that must be produced by the valve spring to keep the roller following the round peak of the cam, the 0.484 *R* shown in Fig. 10. The equivalent weight of all the accelerated parts considered placed at the valve is 0.7635 lb. The valve-spring pressure required at 3000 r.p.m. is 59.8 lb.; at 3200 r.p.m. it is 68.0 lb.; at 3400 r.p.m. it is 76.8 lb. Great care is taken to have the master cam ground to a true radius at the peak of the cam. If the cam generated has any bumps on the peak radius, it is impossible to obtain high-speed operation for two reasons. The irregularities set up synchronous vibrations in the valve springs and the accelerations are immensely increased, making the springs too weak. For instance, if the 0.484-

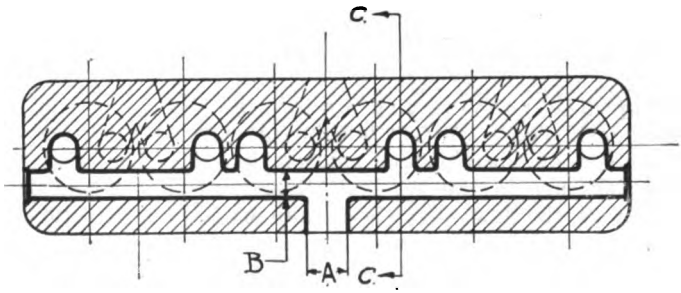

FIG. 14—DIAGRAM OF THE INTAKE-MANIFOLD PASSAGES

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in. peak-radius has waves on it of 3/16-in. radius, the acceleration is increased 116 per cent. These points are mentioned because they are absolutely vital to the successful application of the valve mechanism of the roller type to a valve-in-head engine operated at high speeds.

Fig. 13 gives the inlet-valve timing overlap. This diagram shows that although the inlet-valve is held open fairly late, the valve of another cylinder is close to its maximum lift, preventing a blow-back into the carbureter.

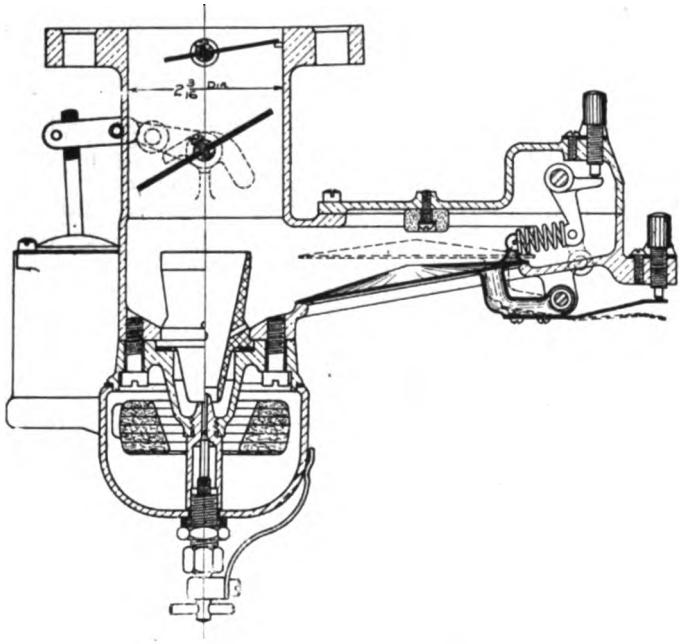

FIG. 15—CROSS-SECTION OF THE CARBUETER USED IN THE TESTS

Fig. 14 shows a diagram of the intake-manifold passages. These are cast within the cylinder-head, making them of the shortest possible length. The engine cylinders fire in the order of Nos. 1, 5, 3, 6, 2 and 4; therefore, the flow of gas is continuous in both directions from the center. The average gas velocity at 3000 r.p.m. at *A* is 181 ft. per sec.; at *B* it is 175 ft. per sec.; just above the valve it is 192 ft. per sec. and at full lift of the valve it is 247 ft. per sec. The throat diameter of

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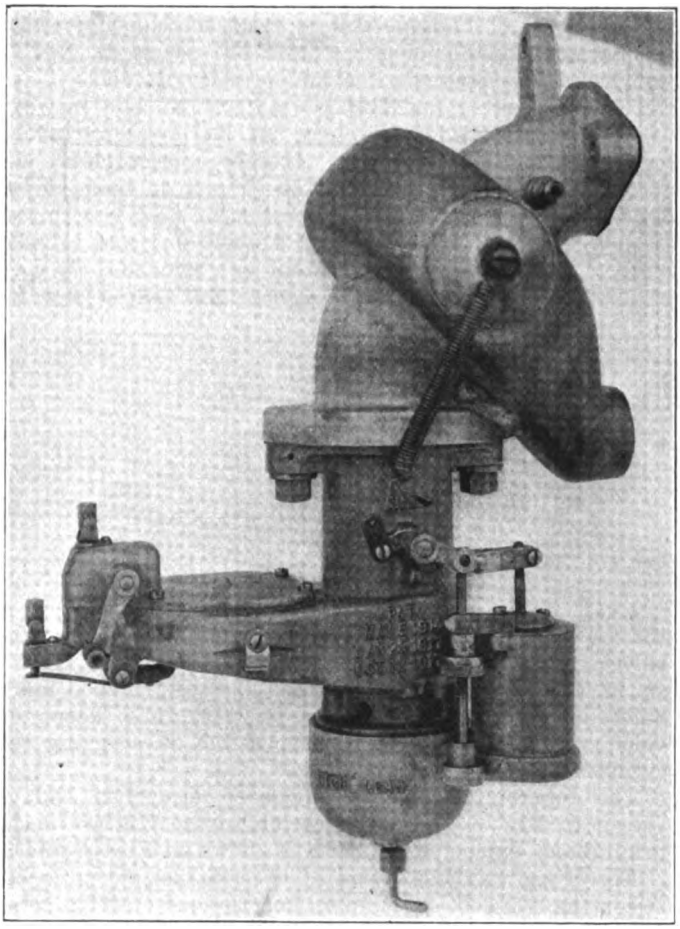

FIG. 16—THE INTAKE-PIPE FUEL VAPORIZER AND CARBURETER SHOWING THE KNURLED THUMBSCREW AND LOCK-NUT EMPLOYED TO ADJUST THE THROTTLE OPENING REQUIRED FOR THE PARTIAL LOAD TESTS CORRESPONDING TO THE CAR REQUIREMENTS

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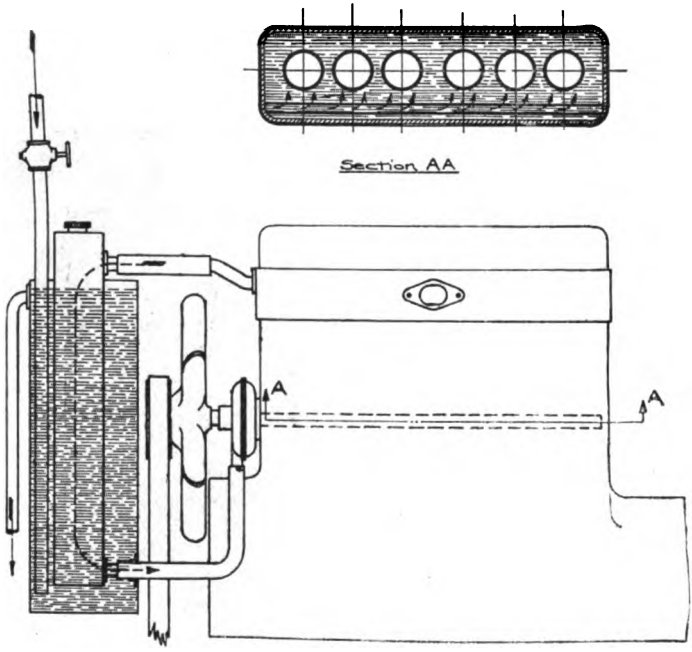

FIG. 17—DIAGRAM OF THE ENGINE COOLING-WATER CIRCULATION AND THE RADIATOR COOLING SYSTEM

the valve is 1½ in.; the outside diameter is 1⅝ in.; the valve lift is 0.445 in. The area at *B*, Fig. 14, is 1.75 sq. in. and at *A* it is 3.39 sq. in. The tulip-shaped inlet-valve is used to lessen the resistance and keep the velocity of the gas as high as possible on entering the cylinder as an aid to turbulence.

The intake-pipe has already been described and is shown in Fig. 6. The application to the engine in the preliminary experimental form is shown in Figs. 7 and 8.

Fig. 9 shows the passage of the exhaust-gas pipe between the two center cylinders and the gas outlet pipe as used in the tests is shown in Fig. 19, the valve at the end of the pipe being left wide open for all the runs. The engine is equipped with a Delco generator and single breaker-point type of ignition, with automatic and manual spark advance. A Willard battery was charged during the tests and also was used for starting. The spark-plug installation is shown in Fig. 9. Champion—Toledo No. A-63 metric two-piece plugs were used for all

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the runs. The perfect operation of these plugs had much to do with the ease with which the tests were run. Only six plugs were used and at the end of the runs they were in perfect condition. This is saying a great deal for the spark-plugs, considering the high-compression pistons, power output and speed of this engine.

Fig. 15 shows the 2-in., Johnson, Model-B carbureter used. The air-valve spring and strangle tube were first worked out for the low-compression piston tests. The same parts worked out nicely in connection with the 5 to 1 compression pistons, with only a slight change of adjustment on the air-valve spring. Otherwise, in each set of tests, all adjustments were kept constant for both partial and full-throttle loads.

Fig. 16 shows the knurled thumbscrew and lock-nut used to adjust the throttle opening required for the par-

FIG. 18—THE CONNECTING-ROD, INLET-VALVE, EXHAUST-VALVE, PISTON-PIN AND PISTONS

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tial-load tests corresponding to the car requirements. The spring shown kept the slack out of the throttle shaft. With the Sprague electrical dynamometer and the fine throttle adjustment, the proper load and speed were obtained readily.

The section at *AA* in Fig. 17 shows the equal distribution of the cooling water to the cylinder sleeves. The water goes from the pump to the tube inside the cylinder block. Two holes for each sleeve give a uniform distribution of the water. This keeps all the sleeves at the same temperature, an important feature for equal gas distribution and smooth running. The engine cooling water circulates through a standard radiator as used on the car. The radiator is cooled by circulating water from an outside source around the outside of the radiator; that is, the cooling medium is water in place of air as used in the car. However, the engine water, having the same resistance as in the car, must have the same temperature drop, for the quantity circulated is the same in each case. The temperature of the engine water is controlled very easily by this apparatus, and is an exact duplicate of car conditions. The temperature of the engine-water outlet was kept at 150 deg. fahr. for all the tests.

Fig. 18 shows a photograph of the connecting-rod, inlet-valve, exhaust-valve, piston-pin and the pistons. The connecting-rod length is 11 in., the weight complete with bearings is 46.35 oz. and the center of gravity is 2.60 in. from the center of the crankpin end. Two pistons are shown at the upper part of the photograph. The one to the left is the 4.25 to 1 compression piston; the one to the right is the 5 to 1 compression constant-clearance type of piston. The view at the bottom shows the latter piston from a different angle. A set of 4.25 to 1 compression pistons of the constant-clearance type was not available for the comparative tests; however, ⅛-in. wide piston-rings were used in each case and the 4.25 to 1 compression pistons were relieved at the side in an endeavor to give the pistons approximately the same bearing area as the other pistons. The cylinder clearance given the low-compression pistons was 0.005 to 0.006 in. and that of the high-compression pistons 0.0015 to 0.0025 in. The weight of three ⅛-in. wide piston-rings is 1.82 oz.; that of the 4.25 to 1 piston, 13.52 oz.; that of the 5 to 1 piston, 18.65 oz.; and that of the piston-pin, 5.60 oz. The weight of the complete engine

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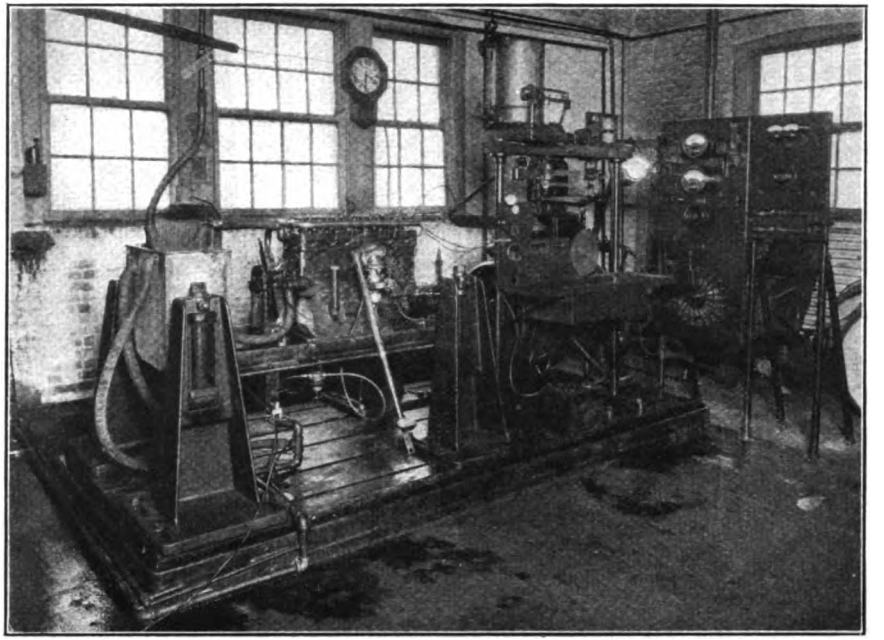

FIG. 19—DYNAMOMETER EQUIPMENT USED

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without the clutch is 660 lb. The weight of the complete powerplant, engine, clutch and transmission is 780 lb.

Testing Apparatus

Fig. 19 shows the Sprague dynamometer equipment. A Weston tachometer was used to indicate the speed. This was checked repeatedly by a revolution counter throughout the entire range of speeds used. The engine cooling-water temperature was obtained by a radiometer calibrated for the range used. The temperature control of the engine-cooling water has already been described, and a diagram of it is shown in Fig. 17. Fig. 19 shows also a view of the radiator installed within the cooling tank.

Particular care was used in weighing the fuel for each run. Two fuel tanks were used, one for a general supply and the other for weighing the fuel consumed in 120 sec. The time interval was obtained from the second hand of a watch and the use of a three-way valve connecting the two tanks to the carbureter. Both tanks were equipped with gage glasses so that the level of gasoline could be kept almost the same. This is important because the height of the level of gasoline in the carbureter bowl is a function of the pressure on the gasoline. It is obvious that, should the level of the gasoline in the carbureter change during the run, the fuel weighed would be in error by the amount of fuel it took to change the level. The main tank is shown at the extreme left of Fig. 19 and the weighing tank and Fairbanks silk scales are shown in Fig. 20. This scale balances readily within 1/100 oz., even when the rubber tubing connected with the fuel line is in place. The small line above the tank is for filling purposes and is connected with the gasoline pump that draws the fuel from the underground tank outside the laboratory. At the right of Fig. 20, the mercury and water manometers are shown. These are connected to the intake-pipe on the engine.

During the tests the windows of the laboratory were opened and the room temperature kept close to 65 deg. fahr. on all the runs. The average barometer readings for comparative tests Nos. 1 and 5 were 30.23 and 30.22 in. of mercury respectively. (See Figs. 21, 24 and 29.) The oil used in the tests was Mobiloil "A." The gasoline used was Target brand, made by the Western Oil Refining Co. The weight of a sample gallon was 96.80 oz. and

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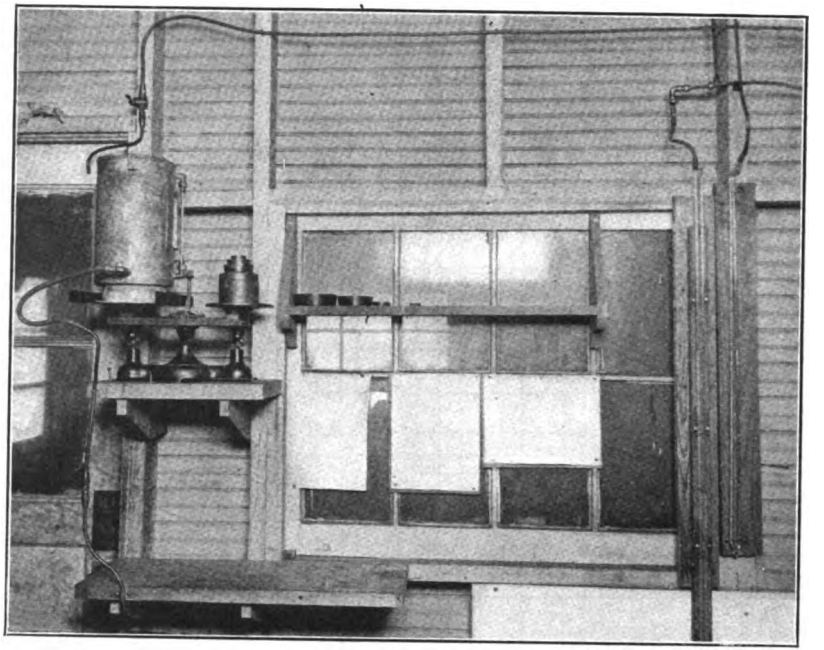

FIG. 20—FUEL WEIGHING SCALES AND MANOMETERS

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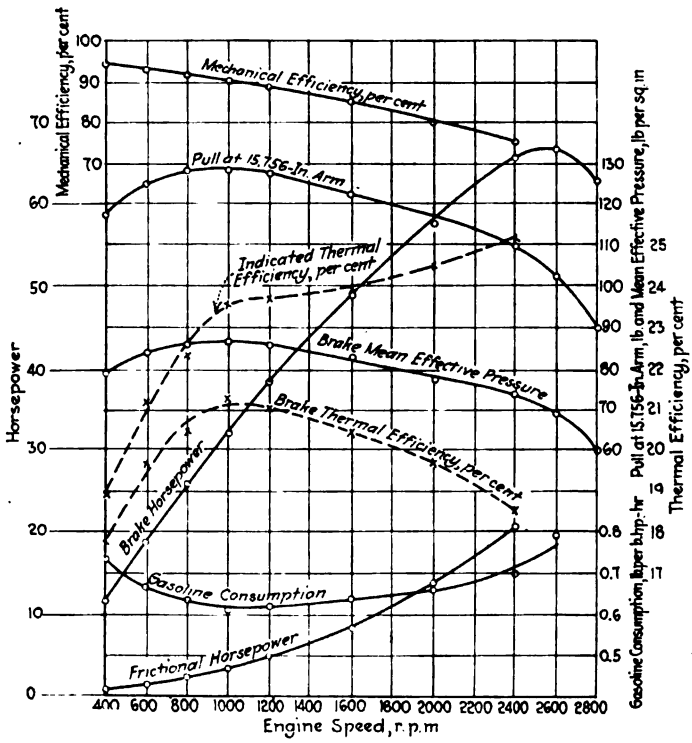

FIG. 21—ENGINE CHARACTERISTIC CURVES OBTAINED WITH AN OPEN THROTTLE AND PISTONS HAVING A COMPRESSION-RATIO OF 4.25 TO 1

the heat value per pound was taken as 19,500 B.t.u. in connection with the calculation of the thermal efficiencies.

COMPARATIVE TESTS

Some of the characteristics of the tests will first be mentioned and then curves will be shown giving the percentage comparison of results. Fig. 21 shows the engine characteristics at full load with the 4.25 to 1 compression pistons. The maximum brake mean effective pressure comes at 1000 r.p.m., with a considerable reduction at 400 r.p.m. due to the delayed inlet-valve timing. The maximum fuel economy is 0.613 lb. per b.hp. per hr. The mechanical efficiency is very good at low speed but drops off rather fast as the speed increases. The peak of the power curve is at 2600 r.p.m.

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Fig. 22 shows the results of tests Nos. 2, 4A and 3, in terms of miles per gallon for 4.5, 3.5 and 2.5 rear-axle gear-ratios and 4.25 to 1 compression pistons. It will be noticed that a material increase in mileage is obtained as the engine load factor is increased by changing the rear-axle gear-ratio.

Fig. 23 gives the engine characteristic under constant-speed driving conditions with 4.25 to 1 compression pistons and 3.5 to 1 axle gears. It will be seen that the full-load brake characteristics have been changed greatly, while the indicated characteristics have suffered but little. The so-called friction losses, which include the pumping and thermodynamic losses, very materially lower the mechanical efficiency. Note that the engine is pumping against an intake-manifold depression of 15

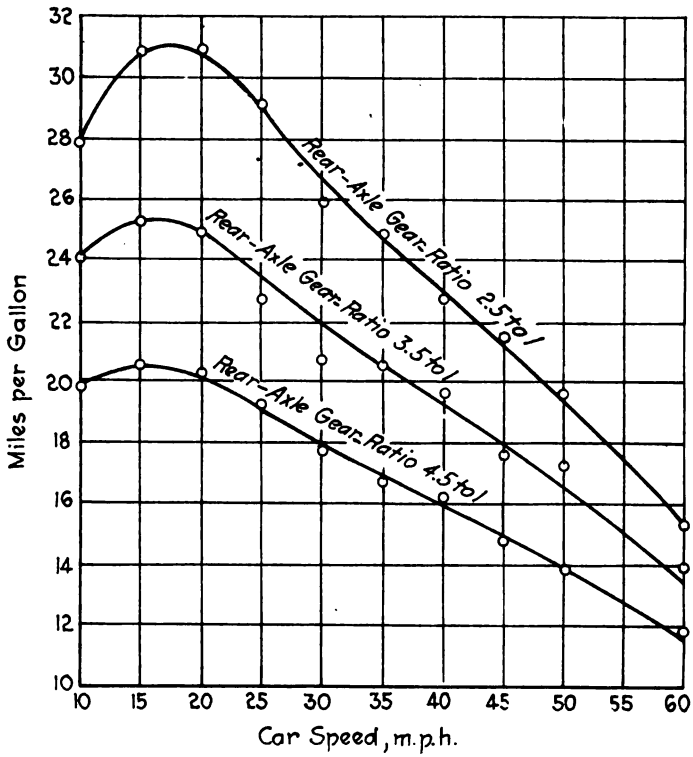

FIG. 22—CURVES SHOWING THE RELATION BETWEEN CAR SPEED AND FUEL-CONSUMPTION USING PISTONS HAVING A COMPRESSION-RATIO OF 4.25 TO 1

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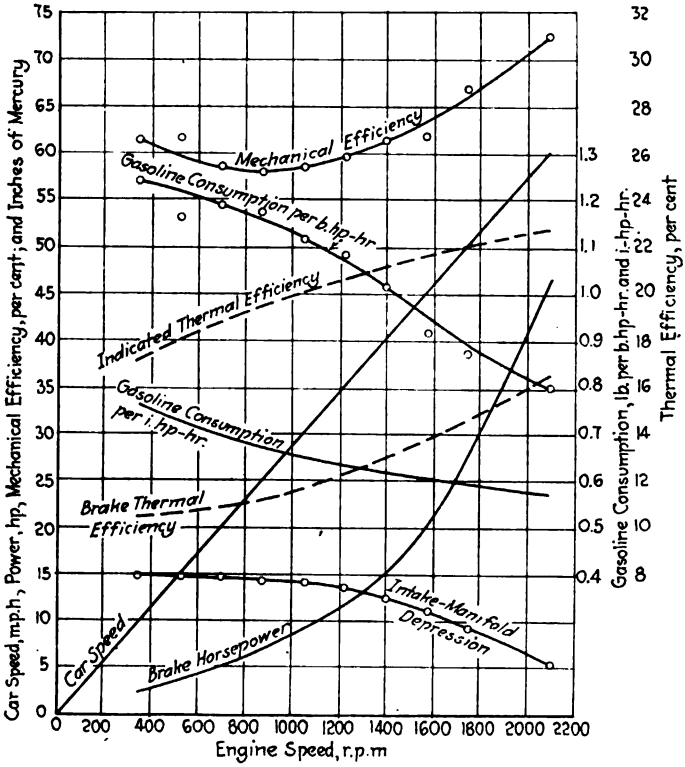

FIG. 23—ENGINE CHARACTERISTIC CURVES OBTAINED WITH A CONSTANT CAR SPEED, A 3.5 TO 1 REAR-AXLE GEAR-RATIO AND PISTONS HAVING A COMPRESSION-RATIO OF 4.25 TO 1

in. of mercury at the lower speeds and the mechanical efficiency at 800 r.p.m. is only 58 per cent, compared with 91.7 per cent at full load.

Fig 24 gives the engine characteristic when using the 5 to 1 compression pistons, everything else on the engine being identically the same. The readings given are not "snap" readings. The engine in all tests was kept running continuously and the results shown are those at which the engine runs with stability; that is, the result to which the engine settles at any given speed. It will be noticed that the maximum brake mean effective pressure is still at 1000 r.p.m., but it has increased from 86.2 to 96.9 as compared with Fig. 21. It will also be noticed that the increase is greater as the speed increases.

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The peak of the power curve comes at about 3100 r.p.m. The fuel economy is greatly increased, being 0.527 lb. per b.hp. per hr. at 1000 r.p.m. as compared to 0.613 lb. per b.hp. per hr. in the case of 4.25 to 1 compression. The mechanical efficiency is shown as not being as good below 800 r.p.m., but it is very much better at the high speeds, being 76.1 per cent as compared with 81.4 per cent at 2400 r.p.m. The maximum brake thermal efficiency is increased from 21.1 to 24.8 per cent.

Fig. 25 gives the engine characteristics in connection with constant-speed driving, with 5 to 1 compression pistons and 4.5 to 1 axle gears. Fig. 26 is for 2.5 to 1 and Fig. 27 is for 3.5 to 1 axle gears. Fig. 27 can be compared directly to Fig. 23, the only difference being the compression-ratios. It will be noticed that the

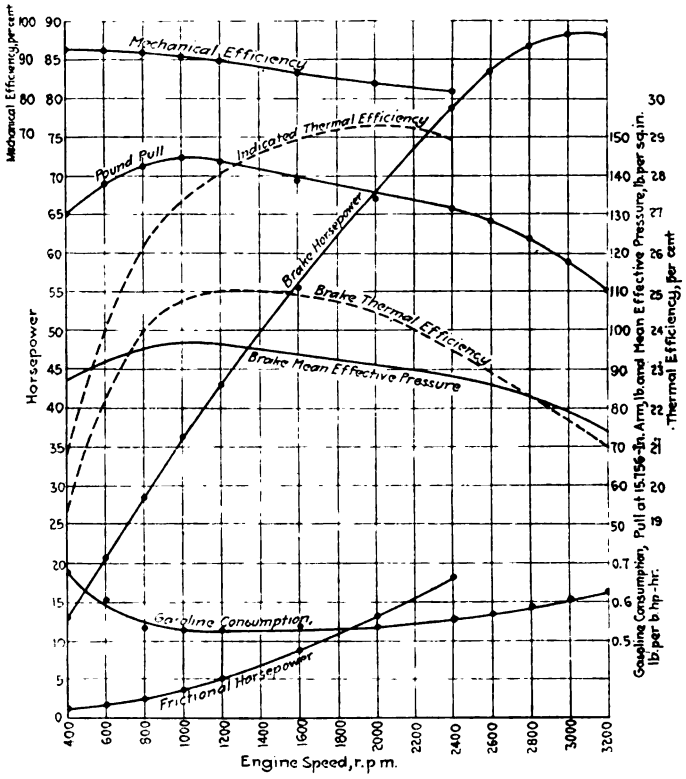

FIG. 24—ENGINE CHARACTERISTIC CURVES OBTAINED WITH OPEN THROTTLE AND PISTONS HAVING A COMPRESSION-RATIO OF 5 TO 1

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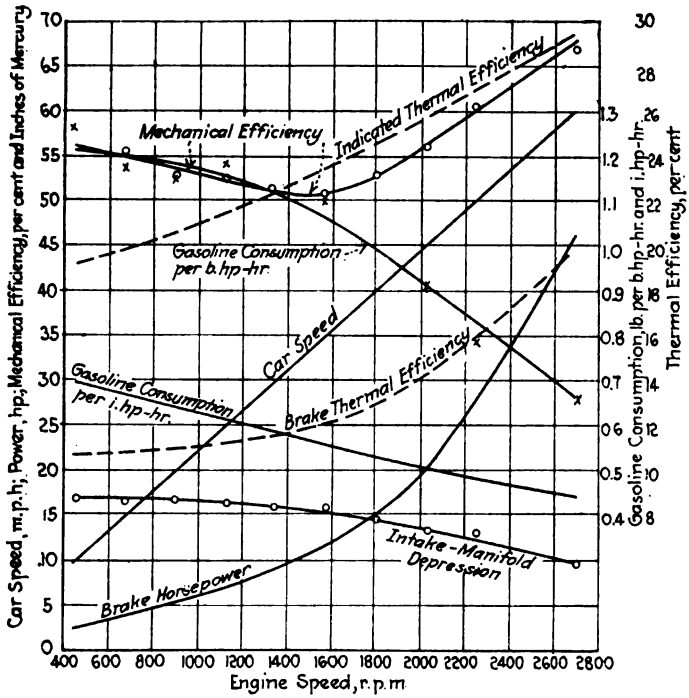

FIG. 25—ENGINE CHARACTERISTIC CURVES OBTAINED WITH A CONSTANT CAR SPEED, A 4.5 TO 1 REAR-AXLE GEAR-RATIO AND PISTONS HAVING A COMPRESSION-RATIO OF 5 TO 1

mechanical efficiency has not been materially changed; however, the fuel economy has been very materially increased. It is very gratifying to note that the relative increases are even greater than those of full-load characteristics. At 1000 r.p.m., the brake thermal efficiency has been increased from 11.5 to 14.1 per cent, and at 2100 r.p.m. it has been increased from 16.4 to 23.2 per cent.

Fig. 28 shows the miles per gallon curves for 5 to 1 compression pistons. This can be directly compared to Fig. 22. The results are materially higher all along the line. The overall increase at 15 m.p.h. is from 16.4 to 31 miles per gal., when changing both the compression and the axle gears.

In reference to what these curves represent, compared with actual road tests, on long road tests the results agree very closely with the curves considering the

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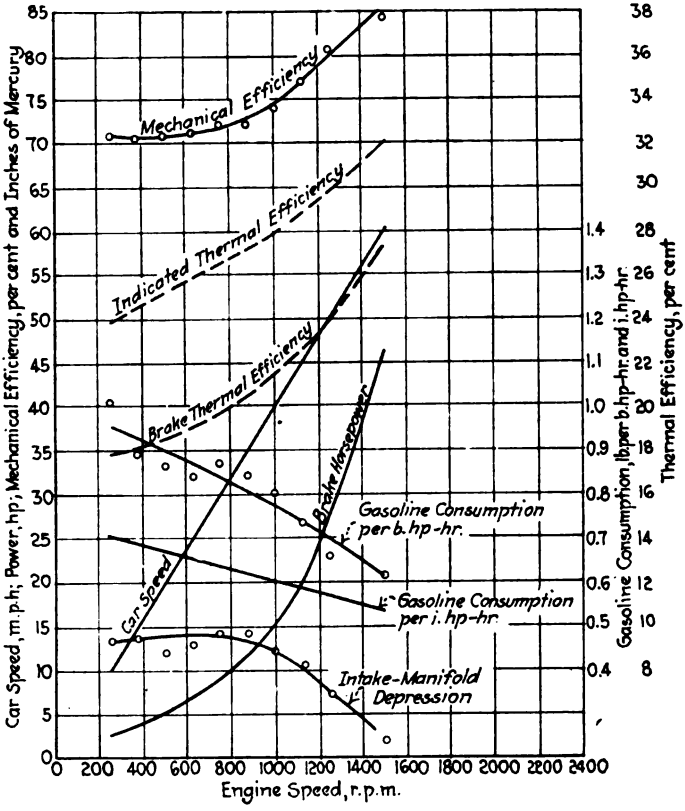
amount of time the engine is idled and the nature of the driving. On the speedway, however, the results can be duplicated at constant driving. They also can be increased in case of using light engine oil and higher tire pressure than those used in the tests to set the standard of brake horsepower required.

Percentage Comparison of Results

Fig. 29 gives the engine full-load characteristics comparison. The comparison as a whole is entirely in favor of the higher compression-ratio, except a very slight loss in mechanical efficiency below 800 r.p.m. The increase in brake horsepower is marked, especially at the higher speeds. The percentage increase in power ranges from



Having a Compression-Ratio of 5 to 1

Fig. 26—Engine Characteristic Curves Obtained with a Constant Car Speed, a 2.5 to 1 Rear-Axle Gear-Ratio and Pistons

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10.5 to 37 per cent, between 400 and 2800 r.p.m. The most important increase is that of the brake thermal efficiency. This ranges from 8 to 26 per cent.

Fig. 30 gives the comparison of the compression-ratio when keeping the rear-axle gears the same; namely, 3.5 to 1. The mechanical efficiency remains practically the same, due to identical engine speeds in each case. The increase in brake thermal efficiency ranges from 19 per cent at 10 m.p.h. to 41 per cent at 60 m.p.h. The saving in gasoline is from 16 to 28 per cent, and, at average driving speed, about 18 per cent.

Fig. 31 gives the comparison of the rear-axle gear-ratios of 2.5 to 1, and 4.5 to 1, using 5 to 1 compression pistons. The percentage increase in mechanical effi-

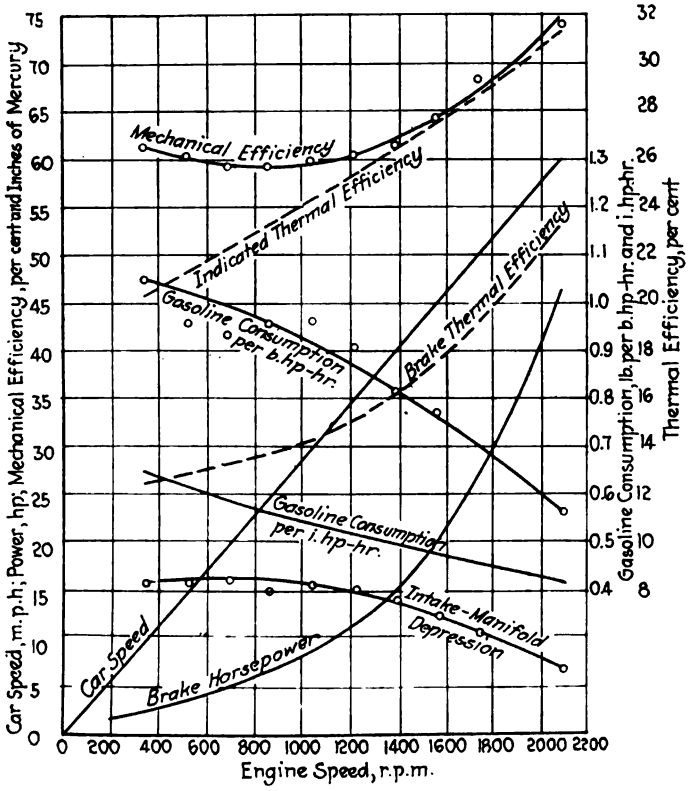

FIG. 27—ENGINE CHARACTERISTIC CURVES OBTAINED WITH A CONSTANT CAR SPEED, A 3.5 TO 1 REAR-AXLE GEAR-RATIO AND PISTONS HAVING A COMPRESSION-RATIO OF 5 TO 1

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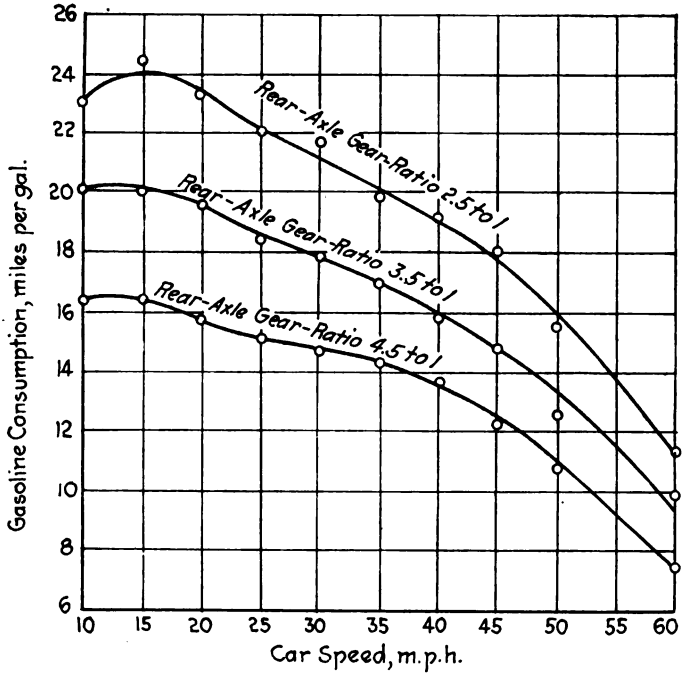

FIG. 28—CURVES SHOWING THE RELATION BETWEEN CAR SPEED AND FUEL-CONSUMPTION USING PISTONS HAVING A COMPRESSION-RATIO OF 5 TO 1

ciency is very marked; the maximum gain is 42 per cent at 36 m.p.h. At 10 m.p.h. it is 27 per cent and at 60 m.p.h. it is 26 per cent. The maximum increase in the brake thermal efficiency is 53 per cent, at 29 m.p.h. It is 48 per cent at 10 m.p.h. and 29 per cent at 60 m.p.h. The gasoline saved is 30 per cent at 10 m.p.h.; 34 per cent at 29 m.p.h.; and 23 per cent at 60 m.p.h.

Fig. 32 gives the percentage increase in miles per gallon in the case of using 2.5 to 1 axle gears with 5 to 1 compression pistons, compared to 4.5 to 1 axle gears and 4.25 to 1 compression pistons. The increase in miles per gallon is 70 per cent at 10 m.p.h.; 95 per cent at 20 m.p.h.; 81 per cent at 30 m.p.h.; 68 per cent at 40 m.p.h.; 76 per cent at 50 m.p.h.; and 104 per cent at 60 m.p.h. These are indeed increases in economy that cannot be passed by lightly, yet they are by no means as great as the economy that is possible. Let us next consider the economy that is possible even with our pres-

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ent engines. For the sake of a name let us call it the "Ideal" economy.

Ideal Economy

We are a long way from the point where we utilize even the economy that is in our present engines. Fig. 33 gives a comparison which throws some light on what is meant. This chart is based on the actual engine economy existing at 60 m.p.h. when using 2.5 to 1 axle gears and 5 to 1 compression pistons. The economy is 0.513 lb. per b.hp. per hr. Using this economy and the brake horsepower required to drive the car at each speed, we derive a curve that we have termed the "Ideal" economy in terms of miles per gallon. It is not meant that this curve is practical with our present system of transmission of the power, but, if the proper gear-ratio and engine size are used for any given speed, this econ-

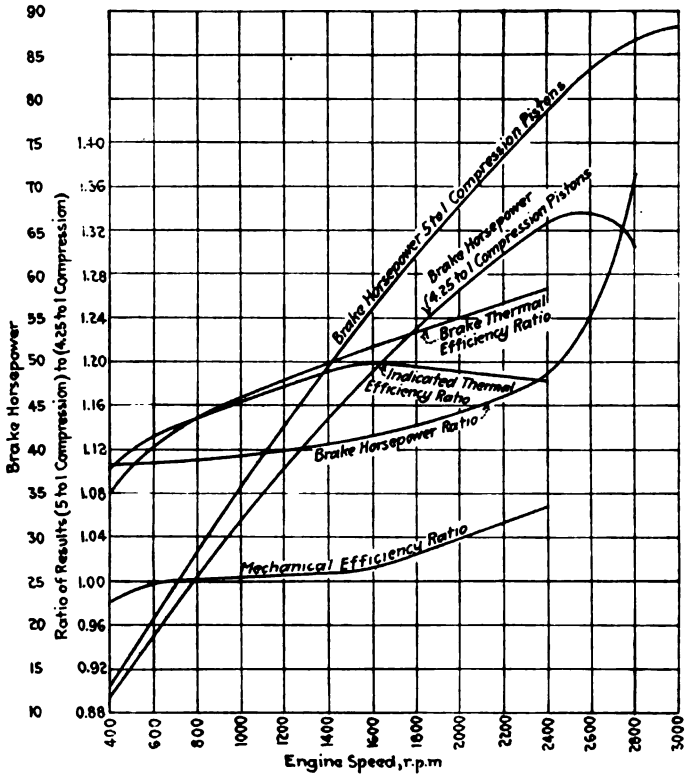

Fig. 29.—A Comparison of the Engine Full-Load Characteristics

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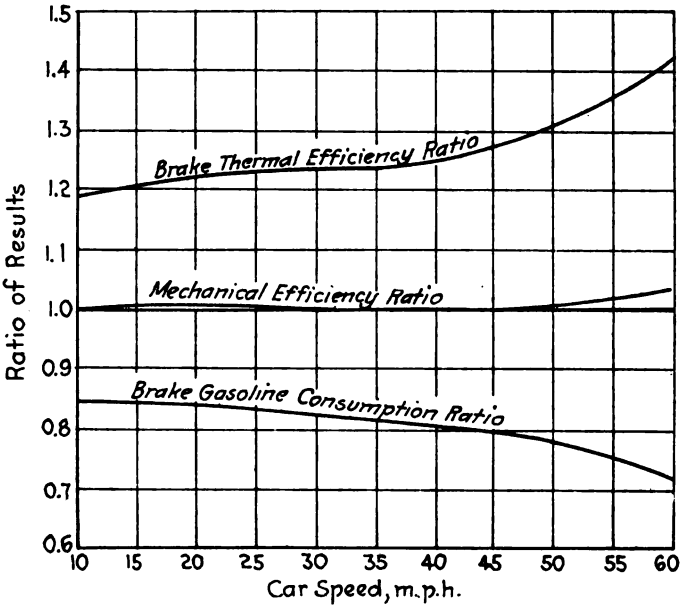

FIG. 30—A COMPARISON OF THE COMPRESSION-RATIOS USING A REAR-AXLE GEAR-RATIO OF 3.5 TO 1

omy can be obtained for the size of car used in these tests. From the ideal curve it will be seen that it is possible to get 49 miles per gal. at 10 m.p.h.; 45 at 20 m.p.h.; 39 at 30 m.p.h., and 31 at 40 m.p.h. The comparison is made with the results of 2.5 to 1 and 4.5 to 1 axle gears, in connection with the 5 to 1 compression pistons.

The increase in the miles per gallon over that of the results with 2.5 to 1 axle gears is 76 per cent at 10 m.p.h. and 45 at 30 m.p.h. The increase over that of the results of 4.5 to 1 axle gears is 146 per cent at 10 m.p.h., 115 per cent at 30 m.p.h. and 36 at 60 m.p.h. Further, the ideal economy comparison with the results obtained from 4.5 to 1 axle gears and 4.25 to 1 compression pistons is an increase of 104 per cent at 60 m.p.h.; 163 per cent at 30 m.p.h., and 199 per cent increase in miles per gallon at 10 m.p.h. These figures certainly are emphatic enough to arouse several changes in viewpoint of our present methods of applying our engines. Evidently there is room for very considerable

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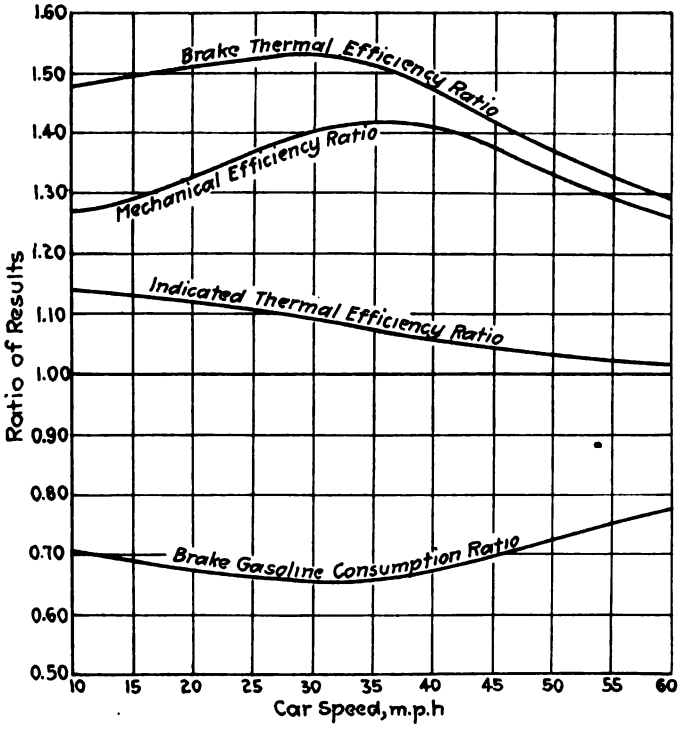

FIG. 31—COMPARISON OF REAR-AXLE GEAR-RATIOS USING PISTONS HAVING A COMPRESSION-RATIO OF 5 TO 1

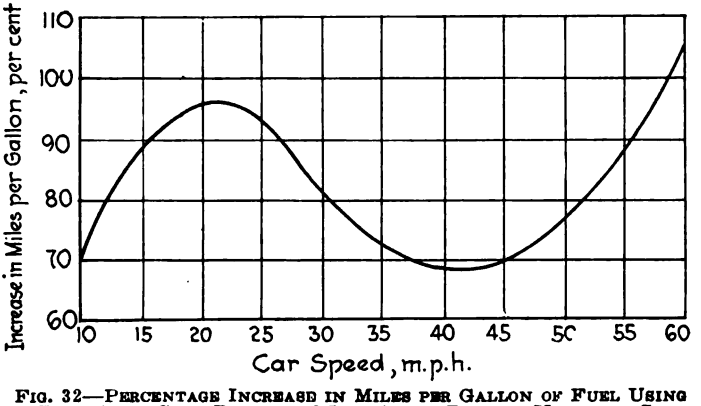

FIG. 32—PERCENTAGE INCREASE IN MILES PER GALLON OF FUEL USING A REAR-AXLE GEAR-RATIO OF 2.5 TO 1 AND PISTONS HAVING A COMPRESSION-RATIO OF 5 TO 1 AS COMPARED WITH A REAR-AXLE GEAR-RATIO OF 4.5 TO 1 AND PISTONS HAVING A COMPRESSION-RATIO OF 4.25 TO 1

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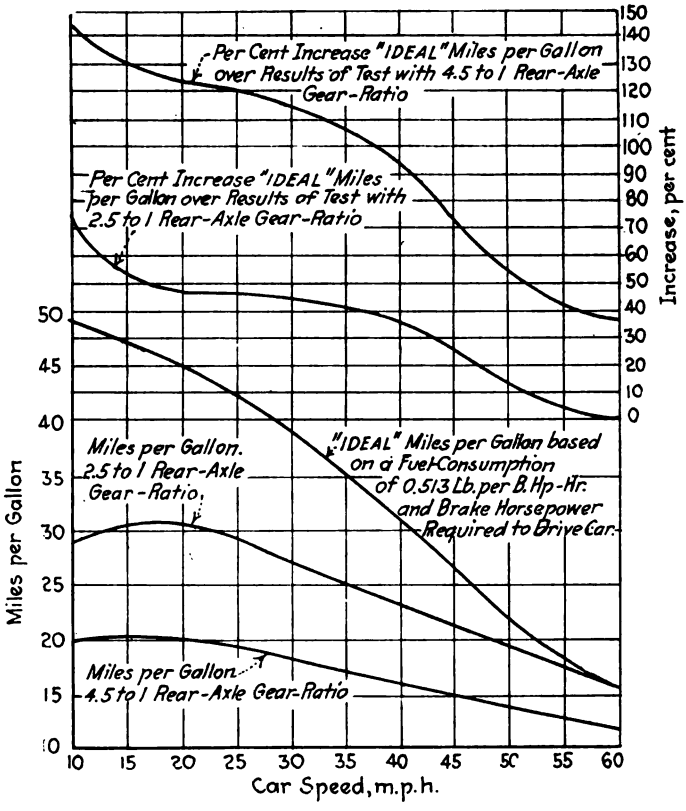

FIG. 33—A COMPARISON OF THE ECONOMY THAT IS POSSIBLE WITH PRESENT ENGINES COMPARED WITH THE RESULTS OBTAINED IN THE TESTS

progress and it is hoped it will be forthcoming in the near future.

It is hoped that the example of correlating important data will be carried out thoroughly in all our engineering investigations, thereby enlarging our viewpoint. Means should be developed making it possible to use very high piston compression-ratios. It is felt certain that it can be done and to a great advantage from the point of economy. It is hoped that very decided progress will be attempted in piston development with a view to overcoming knocking and increasing the general efficiency.

Our viewpoints on fuel vaporizers will, it is hoped, be greatly augmented and, as engines are made smaller to

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increase the load factor, carbureters will be made larger to avoid pumping losses and loss of maximum power. The fallacy that large carbureters are not as flexible or as economical as small ones is based, it seems, on the failure of certain types of large carbureter which it is thought are working on incorrect principles. It is recommended that we test the idea of using large carbureters to operate small engines, rather than that of using large engines to operate small carbureters.

The application of the indicated engine power should be studied from every angle. The tests show that an absurd waste is rampant in our present method. How far our ingenuity can go in this direction is hard to predict. One thing is certain; we must analyze carefully the gains that can be made. A close study from the brake-horsepower standpoint may justify changing both our transmission and our rear-axle drives. The latter combinations, together with engine developments, look the most promising at present. The progress we make undoubtedly will be measured by the extent to which we expand our engineering viewpoint. [The discussion of this paper is printed on page 123.]

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CHASSIS DESIGN FOR FUEL ECONOMY

By A L Putnam[1]

As the engine is the most important unit of a complete automobile chassis, it has had a major share of attention in its development and is far in advance of the rest of the machine as a result. Consequently, at least for the passenger-car engineer, improvements in the automobile as a road vehicle offer greater scope and reward than improvements in engines, particularly as all such improvements are reflected in direct proportion instead of being minimized by adverse operating conditions. The attitude has been common of not worrying about a fraction of 1-per cent loss here and there when such an enormous loss occurs at the exhaust pipe and radiator. Other varying and intermittent losses in the aggregate are not insignificant and, when multiplied by millions of cars, become millions of gallons of fuel and oil.

The author's aim is to call attention to some of these losses, with suggestions as to means and methods of correction. This includes a study of the effects of heavy greases, dragging brakes, relative motion of parts and tire sizes, all of which are discussed at some length.

As the engine is the most important unit of a complete automobile chassis, it has had a major share of attention in its development and it is considerably in advance of the rest of the machine as a result. This is true, notwithstanding the fact that great improvements in engine efficiency are not very evident when the engines are operated under normal conditions of service.

A 10-per cent more-efficent engine placed in a motorboat, airplane or tractor is quite likely to preserve that characteristic, but in a passenger-car chassis it may be no better or even 10 per cent worse due to the wide variation of handling speed and load. All engines are now so good and reliable and require so little attention that a man looking after a car and attempting to keep it in condition for smooth operation spends hours on the other parts and units for every minute he spends on the engine. Also, when the car is put into service on the road, nearly all the attention of the driver and pas-

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sengers is concentrated on the purely vehicular performance of the car with relation to the wide variety of road surfaces, and not on the engine performance. Consequently, for the passenger-car engineer, at any rate, improvements in the automobile as a road vehicle offer greater scope and reward than improvements in engines, particularly as all such improvements are reflected in direct proportion instead of being minimized by a score of adverse operating conditions.

Heavy Greases

The attitude has been common of not worrying about a fraction of 1-per cent loss here and there when such an enormous loss is pouring out of the exhaust pipe and radiator. These other varying and intermittent losses in the aggregate are not insignificant and when multiplied by millions of cars become tens of millions of gallons of fuel and oil. My aim is to call attention to some of them with suggestions as to means and methods of correction. The anti-friction bearings themselves give very little chance for any considerable improvement. But the practice of using a very heavy grease in the transmission and rear-axle which solidifies at even a cool temperature from the standpoint of fuel economy and efficient lubrication is far from economical. This is particularly the case when the car is frequently stopped and started and used intermittently in very cold weather. Accurate data can, of course, be secured on this point by driving the transmission or the axle by an electric motor at different temperatures with heavy "dope" or thin engine oil as a lubricant and I am sure the results would be rather informing. The various very good and important reasons which have resulted in the building up of this heavy-dope practice have so nearly disappeared that they can all be overcome. It is now perfectly possible to make and install gears which will pass as to sound even if not smothered by dope. It is also possible to construct properly vented transmission cases and differential housings which will hold thin oil with even less leakage than we have at present with the thick.

Dragging Brakes

The great congestion of traffic in cities, towns and in fact almost everywhere has brought about a very common custom of insistence on a brake adjustment which gives instant action with a very small pedal movement. This condition the external-band brake is a very poor instru-

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ment to fulfill. It is virtually impossible as a matter of common practice to adjust it closely enough to suit and still not drag some. As the quick brake must be had at any cost, the larger number are dragging. A dragging brake which does not heat enough to call attention to itself by developing excessive heat at a moderate speed still has a marked effect on the position of the throttle and is a very clever scheme to burn gas. Brakes are at this minute, I am sure, pulling from a mere fraction to several horsepower per pair out of the majority of cars equipped with them. The internal-expanding type of brake is much better adapted to extremely close adjustment without dragging and the heat it generates expands and contracts the drum in the right direction with relation to the shoes instead of the wrong direction as in the case of the external-band brake.

You probably all recollect statements which have appeared from time to time in the press by enthusiastic writers that we no longer have horseless carriages but something entirely different and on a much higher mechanical plane than a road vehicle. I have implicitly believed this; I was undeceived this summer in Cincinnati. The company there which transports passengers from one railroad station to the other is not yet fully motorized. It has some light motor buses and some horse-drawn buses which operate at equivalent speed over a vile series of Belgian-block-paved streets. I made the trip one way in a motor bus and the other in the horse-drawn bus. The trip in the latter was so much more smooth and comfortable even with its steel tires and freedom from the bumping, pitching, and sidesway that the pneumatic-tired motor bus had, that after alighting I compared the two vehicles and their construction. This inspection convinced me that we had stuck pretty closely to the old horse carriage and were using all its old stuff with a few extras of our own added for good measure.

Relative Motion of Parts

The main extra the automobile has incorporated is really an extra vehicle. There is one vehicle consisting of wheels, axles, springs, torque-rods, truss-rod, etc., disposed so as to permit of the maximum amount of displacement or separation from the engine frame and body. This engine is asked to transmit its power smoothly and quietly to the wheels and axles which are constantly trying to escape from it and at times taking a very considerable degree of variation in position with relation to it.

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All these vagaries the engine is asked to furnish the power to produce and it takes some power to lift a 2000-lb. body and load 3 in. up and 4 in. down from the normal position and keep on doing it. Just hitch up an engine on the rear end and let it do that one job only. I am sure the power required is sufficient to measure. It was found out centuries ago that horses could not do it and do anything else. Because we have a source of power that does not sweat and lather is not a reason we should continue present practice.

The excessive amount of motion between the engine and the axle, of course, causes a loss of power and fuel in a minor degree due to joint angularity which produces wear; it takes power to produce wear. I think that this excessive amount of movement, no matter how smoothly accomplished, is not, strictly speaking, a comfortable one for the passengers, and know that it is very fatiguing for the driver, increasing greatly the strain of guiding the vehicle.

We have all probably noticed the small power-trip-hammers with the hammer mounted on a leather strap that is shackled to a semi-elliptic spring and the whole head moved up and down by a crank. We have also noticed how the hammer keeps on striking energetically long after the crank has ceased to move it. This trip-hammer is a very good illustration of the action of the axles and springs under the modern automobile and the powerful reactions they give; the engine producing these reactions by furnishing the power to roll over the uneven road surface.

As the weight of the parts in question is on the average about one-quarter of the total weight, they are able to cause considerable disturbance in the smooth operation of the vehicle. This fact is, of course, so generally appreciated that many serious endeavors are made to reduce appreciably the weight of these unsprung parts and by so doing decrease the effect of their action and reaction. These efforts undoubtedly have good effect when they are carried far enough to make an appreciable change in the proportion of sprung and unsprung weight.

Effect of Tire Sizes

No matter what is done to decrease the unsprung weight, the effort starts with a fundamental handicap due to a certain other series of standards. This was called very forcefully to my attention by the declaration

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of the Tire and Rim Association that the 3½, 4, 4½ and 5-in. tires cover adequately the passenger-car field. This is true no doubt in a narrow sense, but from the standpoint of fuel economy and vehicle efficiency is the pneumatic tire doing all it possibly can? The pneumatic tire is one of the main factors in the success of the passenger automobile. If this tire is such a good thing, why not have a little more of it? Why not give it a larger opportunity to show its worth and itself absorb a larger proportion of the shocks, and give better traction?

Years ago the taximeters came off the rear wheels by law because the rear wheels could accumulate mileage at an astonishing rate. They, of course, use fuel to do it; all rear tires are making much more mileage than the vehicle on some classes of roads and there are thousands and thousands of miles of such roads on which the skipping and spinning is so marked as to affect the throttle position for a certain speed enough to call this to the attention of a not very observing driver. This condition is wasteful of fuel and of the rubber tread as well. The main factor in producing this loss of traction and violent action and reaction on the unsprung weight is the proportional tire cross-sectional size and accompanying air pressure for a given load.

The necessary high air-pressure to support the load without injurious deflection of the tire makes the tire so hard and produces such violent reaction when hitting inequalities in the road that the spinning and chattering of the rear tires constitute on many classes of road a very large item of fuel loss, tire destruction and speed. The exceedingly hard small tire is also the instigator of the use of the complicated heavy and highly flexible spring suspension. Given a series of tires of the same outside diameters but considerably increased cross-section for the same load, the air pressure can be cut down safely and a condition produced in which a larger proportion of shocks is absorbed at the source, less slipping and spinning of wheels occur and better traction for starting, running and braking without putting the spring suspension into play so much, is secured.

In fact it is perfectly possible to carry this idea far enough to eliminate the springs entirely and simply provide for the horizontal displacement of the front wheels with relation to the rear pair. When this is done the unsprung weight factor will have disappeared, as all the weight is sprung weight and completely tied together

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without movement. The wheels move with the body and the body with the wheels.

At present we seem to be accepting as gospel the statement that the present tire sizes as put forward are the last word as regards pneumatic-tire equipment, when a little thought and even less science can prove them as only the beginning of the real use of pneumatic tires. [The discussion of this paper is printed on page 90.]

A PRINCIPLE OF ENGINE SUSPENSION

By S E Slocum[1]

Among new developments in the automotive field there is none which offers greater possibilities than the redesign of the engine suspension to eliminate vibration. The problem of overcoming vibration is related closely to the fuel problem, for vibration is responsible for a much greater loss of power and a consequent increase in fuel consumption than ordinarily is supposed. The common impression seems to be that, while vibration is undesirable, it absorbs but a small amount of power. This is not substantiated by actual facts.

Two instances are given to show what large power losses may result from vibration in certain cases. One is that of an automobile engine which had a badly balanced crankshaft; the other, an experiment with an electric motor mounted on a wooden table, the idea being to reproduce the condition of a machine mounted on the upper floor of an ordinary wooden building.

After a description of these two studies, the thought passes to other disastrous effects of excessive vibration and the consideration of critical speeds at which the most serious losses due to vibration occur.

The causes and types of vibration and the elimination of vibrations due to synchronism are discussed in considerable detail, followed by an illustration and an account of one method of applying this principle to automotive apparatus.

Among new developments in the automotive field, there is none which offers greater possibilities than the redesign of the engine suspension to eliminate vibration. The question of overcoming vibration is closely related to the fuel problem, for vibration is responsible for a

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much greater loss of power and a consequent increase in fuel-consumption than ordinarily is supposed. The common impression seems to be that, while vibration is undesirable, it absorbs but a small amount of power. This is not substantiated by actual facts. Two instances are given to show what large power losses may result from vibration in certain cases. The first is that of an automobile engine which had a badly balanced crankshaft. In a road test it was found that the limiting speed for this car was about 20 m.p.h. and that it was impossible to climb a certain hill in high gear. After the crankshaft had been balanced, no other part of the engine having been touched, the limiting speed of the car was found to be doubled and the hill that previously could only be climbed in intermediate gear could be taken easily in high.

The second instance is an experiment made by Professor Sommerfeld in 1902, and published in *Zeitschrift des Vereins Deutscher Ingenieure,* page 391, in which he clearly demonstrated the loss of power due to vibration, also determining the actual percentage of loss that may occur in extreme cases. In this experiment an electric motor was mounted on a wooden table, the idea being to reproduce the condition of a machine mounted on the upper floor of an ordinary building. When the speed of the motor was 310 r.p.m. the table began to vibrate excessively. When this vibration of the table was artificially checked, the motor instantly increased its speed, and when the table was again released, it no longer vibrated. The speed of the motor was therefore limited by the vibration of its support. When the speed of the motor was doubled, the centrifugal force, of course, was increased four-fold, and yet the table suddenly ceased to vibrate, the reason again being that the critical speed had been passed. The speed of 310 r.p.m. at which the table began to vibrate excessively was attained with a power supply of 10 watts. An increase in the power supplied merely increased this vibration without increasing the speed of the motor. In fact the speed remained practically constant at 310 r.p.m., until the power supply rose to 30 watts. In this case, therefore, two-thirds of the power supplied at this speed was absorbed in the vibration of the support. These experiments indicate not only how much power can be absorbed by vibration, but also that this power loss may be due to supporting a machine on a badly designed foundation.

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That is, at certain speeds, the support itself if improperly designed may absorb a considerable percentage of the indicated power.

In addition to power losses, excessive vibration has various disastrous effects. The continued reversal of stress in a vibrating body produces fatigue of the material and ultimately results in the failure of the part. This is a fact of common occurrence in all types of machinery. In the case of large machines mounted on heavy concrete foundations, such as turbo-generators, vibration results in disintegration of the concrete, allowing the machine to settle out of alignment. In electrical machinery, vibration causes poor commutation, often to such an extent as to result in serious electrical losses. These are a few instances of the waste of energy in vibration, and its destructive effects.

Critical Speeds

The most serious losses due to vibration occur, of course, at the so-called critical speed. There seems to be considerable misunderstanding as to just what is meant by critical speed. What it amounts to is that every elastic body, if displaced from its position of equilibrium and then released, will oscillate about this position with a certain definite frequency or period. This oscillation, or vibration, dies out more or less quickly, depending upon the molecular and other resistances. Such oscillations which a body performs of itself are called natural or free oscillations, and the period of such oscillations or the length of time required to make one complete oscillation is called the natural period of the body.

A body may also be forced to oscillate by the action of an impressed periodic force; that is, by an external force which recurs at equal intervals of time. For example, suppose that a shaft mounted in bearings carries an eccentric weight. When the shaft is revolved at any given speed this eccentric weight produces a centrifugal force, which produces kinetic reactions at the bearings and thereby causes the supporting system to oscillate back and forth. This forced oscillation of the supporting system, of course, has the same period as the speed of revolution. Suppose that the speed of revolution is altered until the period of this forced oscillation of the supporting system is identical with its natural or free period of oscillation. In this case we say that the two

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periods synchronize. The result of such synchronism is to intensify the vibration greatly and, although in any actual case the amplitude of vibration cannot exceed a certain limiting value, it frequently becomes so large as to cause failure of certain parts or even tear the machine from its supports.

By critical speed, then, we mean that speed of the rotor which synchronizes with the natural frequency of oscillation of the supporting system; that is, the critical speed is reached when the number representing the revolutions per minute of the rotor becomes identical with the number representing the number of oscillations per minute which the supporting system would perform if set in vibration and left to itself.

Every elastic body has more than one natural period of oscillation. The vibrations corresponding to these higher periods are called harmonics. A familiar illustration is that of a violin string which, in addition to its fundamental note, can be made to sound overtones or harmonics by stopping the vibration with the finger at certain definite points called nodes. Every elastic system possesses such harmonics. Consequently, there is always more than one critical speed, the higher critical speeds corresponding to synchronism with these harmonics. It should be mentioned that these higher critical speeds are not simple multiples of the lowest critical speed, but bear a more complex relation to it, depending upon the nature of the system.

Causes and Types of Vibration

When vibration is due to centrifugal forces and centrifugal couples arising from unbalance, it can, of course, be reduced or eliminated altogether by balancing the rotating parts. But there are other causes for vibration which cannot be eliminated so easily. For instance, in an eight-cylinder V-type engine, a perfectly balanced crankshaft will not result in a perfectly balanced engine, as there are certain inertia forces arising from the reciprocating and semi-rotating parts which are not affected by balancing the purely rotating elements. Moreover, vibration due to synchronism is entirely distinct from vibration due to unbalance. The effect of unbalance is to produce kinetic reactions which are taken up by the supporting system, causing it to shake violently or vibrate. Whenever vibration is due to unbalance, it can always be traced to the kinetic reactions ap-

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plied at the bearings of the rotor. Synchronism is a broader term and includes vibrations not due to unbalance or only indirectly due to it. Vibration due to synchronism may even affect machines which are not running. For instance, in one case at least it was found that the discs of a turbine rotor were vibrating, or fluttering, although the turbine was not in operation. This, of course, was due to synchronism between the natural period of the turbine disc and the operating speed of adjacent machinery. A perfect example of vibration due to synchronism is the response of a wireless receiving set to the vibrations sent out by the generating station. Clearly, such forced vibrations are due to pure synchronism and have no relation whatever to unbalance.

In the case of machinery, vibrations due to unbalance are often confused with those due to synchronism. The first essential to an intelligent understanding of this whole problem is to make perfectly clear the distinction between forced vibrations due to the kinetic reactions arising from unbalance and forced vibrations due to synchronism. For instance, it is perfectly clear to every one that an unbalanced rotor must produce some vibration of the supports, and that this vibration must be present at every speed, although, of course, it is worse at some speeds than at others. Now this supporting structure, which we will call structure No. 1, rests at certain fixed points in some kind of foundation, which we will call structure No. 2. At certain definite speeds, such as we have called the synchronous speeds, the vibration of structure No. 1 is communicated through the points of support to structure No. 2, and this effect does not depend on what causes the vibration of the first structure. We can, therefore, make the distinction that the vibration of structure No. 1 is produced by kinetic reactions due to unbalance; whereas, the vibration of structure No. 2 is due to synchronism with structure No. 1, independently of what causes the first structure to vibrate.

Elimination of Vibrations Due to Synchronism

When vibration is due to synchronism it is obvious that the cure is to destroy this synchronism. In the case of automotive apparatus, this means that a new principle of engine suspension must be introduced. For stationary machinery the same result can be accomplished by applying this new principle to the design of the understruc-

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ture. The latter was discussed in a paper by N. W. Akimoff, presented at the annual meeting of the American Society of Mechanical Engineers, December, 1920.

The customary method of suspending an engine or mounting a machine consists in anchoring it down firmly to a support designed to be as rigid and massive as possible. There is no attempt to destroy synchronism, the idea being simply to reduce the amplitude of the motion as much as possible. But, in automobiles and aircraft, the entire support is elastic and comparatively light, the result being that the whole structure vibrates freely with the same period as that of the engine. Moreover, in the case of heavy machinery rigidly anchored to heavy foundations, although, of course, the amplitude of the motion is decreased, the mass that is set in vibration is greatly increased, so that we now have the case of a large mass vibrating with a small amplitude. Since the energy absorbed is proportional to the mass of the body, it is evident, particularly in the case of synchronism with the support, that the power loss is not cut down exactly in the same ratio as the amplitude is reduced. It is mentioned in passing that this question of synchronism is one of the vital problems in electrical engineering at present.

It is obvious that the true solution of such problems can only consist in destroying this synchronism by isolating a machine from its support so far as the transmission of vibrations is concerned. To explain what this implies, it is pointed out first that any body may have at most six degrees of freedom; that is, it may be free to move along any three mutually perpendicular axes, giving three degrees of freedom, and it may also be free to rotate about these three axes, giving the remaining three degrees of freedom. If one point of the body is fixed, this destroys the first three degrees of freedom since the body can no longer move as a whole in any direction; but it is still free to rotate about any axis through the fixed point, so that it still possesses three degrees of freedom as regards rotation.

To apply this to the present case, suppose that one point of an engine or a machine is fixed, so that it can pivot about this point. Suppose that, in addition to this one fixed point, two other points of the machine are mounted on resilient supports. It then is evident not only that the machine will have three-point support, but also that within certain limits it will have freedom of

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motion about the fixed point, due to the resiliency of the other two supports. This type of three-point support, one point being rigidly fixed and the other two supports being elastic or resilient, leaves the body three degrees of freedom, and yet makes it possible to control the period of the vibration absolutely. In other words, by properly designing or adjusting these resilient supports it is possible to change the period of vibration so as to prevent any possibility of its synchronizing with the natural period of the engine bed or foundation.

Application to Automotive Apparatus

Fig. 1 shows one method of applying this principle to automotive apparatus. The method used in this case consists in mounting the engine in a cradle, and supporting this cradle on the chassis at three points. The rear support is here the rigid point of the three, and in this case is placed directly underneath the transmission. The two forward supports are the resilient ones and are formed by interposing coiled springs between the cradle and the chassis. A special form of double telescoping spring is used, which permits vibrations of very small amplitude, but is very rigid as regards road shocks. In fact, the action of the resilient supports is exactly the opposite of the ordinary shock-absorber. The supports absorb vibration but do not respond to road shocks.

This method of suspension absolutely isolates the machine from synchronism with its support and, therefore, not only prevents vibration of the support itself but also prevents such vibration from reaching other parts or structures connected with the same support. There are also other lesser advantages of this type of suspension. For instance, in the case of tractors it is found that with four-point, and even with three-point rigid support, it is not uncommon for the engine lugs to snap off. Two resilient supports, however, give what can be called a full-floating suspension, and relieve the crankcase of any abnormal strains to which it may be subjected when all the supports are rigid. It should be mentioned again that the resilient supports are actually very stiff, although not rigid in the same sense as the frame itself, their purpose being to prevent synchronous vibration, but not to permit relative motion to any extent.

There have been several attempts to solve this same problem by using various forms of spring suspension, but none has been based on the scientific principle here

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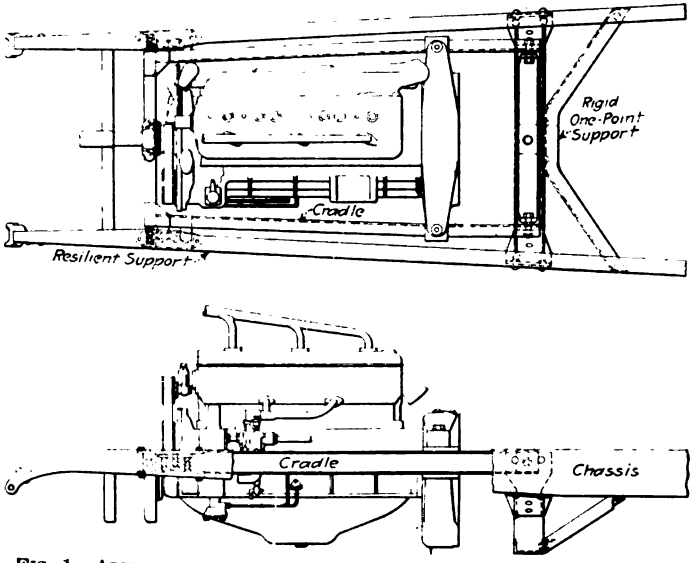

FIG. 1—APPLICATION OF THE THREE-POINT PRINCIPLE OF SUPPORT TO AUTOMOTIVE APPARATUS

used, which consists in destroying three degrees of freedom and allowing the other three to remain. For instance, one man tried three spring supports, another tried four and a third used a cradle mounted at the rear end on an axle transverse to the frame with two spring supports at the forward end, thereby allowing but one degree of freedom. Such forms of suspension cannot yield satisfactory results, as they are wrong in principle. It is apparent from what precedes that the principle underlying the design here described is radically different.

To sum up therefore, we may say that there are two main types of vibration, one due to unbalance and the other to synchronism. The first can be eliminated by well-known methods of balancing, leaving only the vibration due to torque recoil and inertia forces. The second can be eliminated by preventing synchronism, and this can be accomplished by introducing a new type of three-point suspension. The underlying principle consists in controlling the period of vibration by two resilient supports. It should be noted that this method of suspension supplements, but does not replace, careful balancing of all rotating parts and that its use will improve the performance of any type of engine, although most needed by the four and eight-cylinder types. [The discussion of this paper is printed on page 90.]

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COMPRESSION-RATIO AND THERMAL EFFICIENCY OF AIRPLANE ENGINES

By S W Sparrow[1]

Appreciating the fundamental relation of the compression-ratio to the thermal efficiency, the National Advisory Committee for Aeronautics sponsored a comprehensive investigation of this subject at the Bureau of Standards. Every effort was made to measure the engine performance so completely as to make possible an analysis that would not only explain the results of this particular series of tests but form a sound basis for predicting the effect of changes in the compression-ratio on the thermal efficiency of any engine. The experimental work is as yet incomplete and only some of the more salient results are presented in this paper.

An eight-cylinder airplane engine was used, having pistons allowing compression-ratios of 5.3, 6.3, 7.3 and 8.3. The differences in compression-ratio were effected by crowning the piston-heads by different amounts. The tests were made in the altitude-chamber to secure typical altitude conditions of air temperature and pressure, and those presented in this paper were made under full load at an engine speed of 1600 r.p.m. The resultant data are exhibited in charts and these are analyzed.

It is only recently that the old definition of an engineer as "one who can do with one dollar what any fool can do with two" could be applied appropriately to the aviation engineer. His task has been rather to do, at any cost, what "any fool" could not do at all and to his success the aeronautic achievements of the past year bear testimony. Now, however, it is assumed that the aviation engine will be reliable and of not unreasonable weight per horsepower, and the demand becomes one for higher efficiency or more miles per dollar. Foreseeing this demand and appreciating the fundamental relation of the compression-ratio to the thermal efficiency, the National Advisory Committee for Aeronautics has sponsored a comprehensive investigation of this subject at the Bureau of Standards. Every effort has been made

[1] M.S.A.E.—Mechanical engineer, automotive powerplants section, Bureau of Standards, Washington.

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to measure the engine performance so completely as to make possible an analysis which will not only explain the results of this particular series of tests, but will also form a sound basis for predicting the effect of changes in the compression-ratio on the thermal efficiency of any engine. Although not even the experimental work is entirely finished, it seems wise to present some of the more salient results at this time rather than withhold them for the more complete analysis.

For these tests an eight-cylinder airplane engine having a bore of 120 mm. (4.72 in.) and a stroke of 130 mm. (5.12 in.) was secured. Pistons were provided giving compression-ratios of 5.3, 6.3, 7.3 and 8.3. These had all been run-in in their respective cylinder blocks to in-

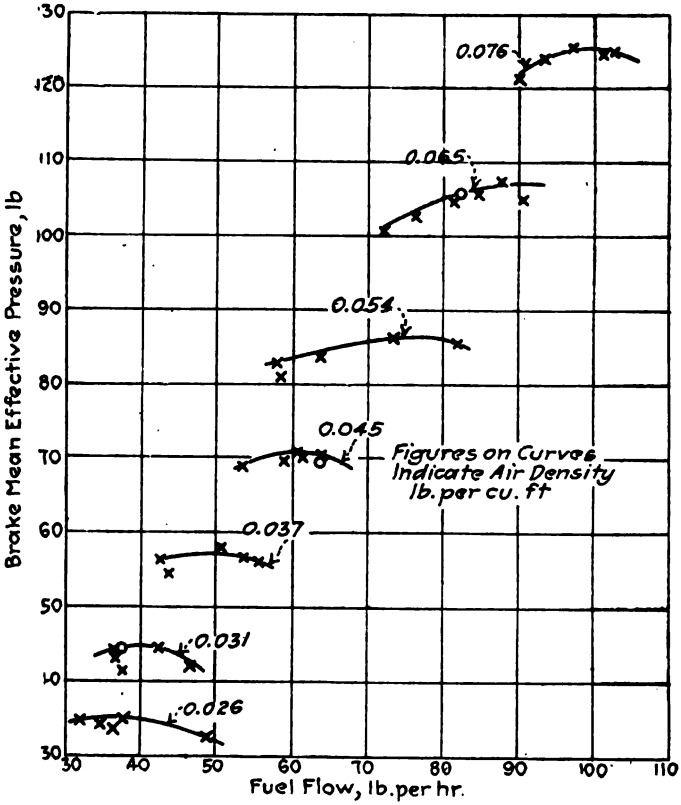

FIG. 1—COMPARISON OF BRAKE MEAN EFFECTIVE PRESSURES DEVELOPED WITH VARIOUS COMPRESSION-RATIOS FROM THE SAME AMOUNT OF FUEL

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sure a proper fit. The differences in the compression-ratio were effected by crowning the piston-heads different amounts. The tests were made in the altitude-chamber of the dynamometer laboratory in order that typical altitude conditions of air temperature and pressure might be obtained.

The tests which have been selected for consideration in this paper were made at full load with an engine speed of 1600 r.p.m. The temperature of the air entering the carbureter was in one case + 10 deg. cent. (50 deg. fahr.) and in the other — 10 deg. cent. (14 deg. fahr.). For each compression-ratio the results were plotted in the manner shown in Fig. 1. This shows the brake mean effective pressure developed with different rates of fuel flow at altitudes from the ground to 30,000 ft. Although these curves show the effect of the air-fuel ratio on power, their real purpose was to make possible a comparison of the brake mean effective pressures developed with the various compression-ratios from the same amount of fuel.

The air measurements showed that practically the same mass of air was taken per stroke with each compression-

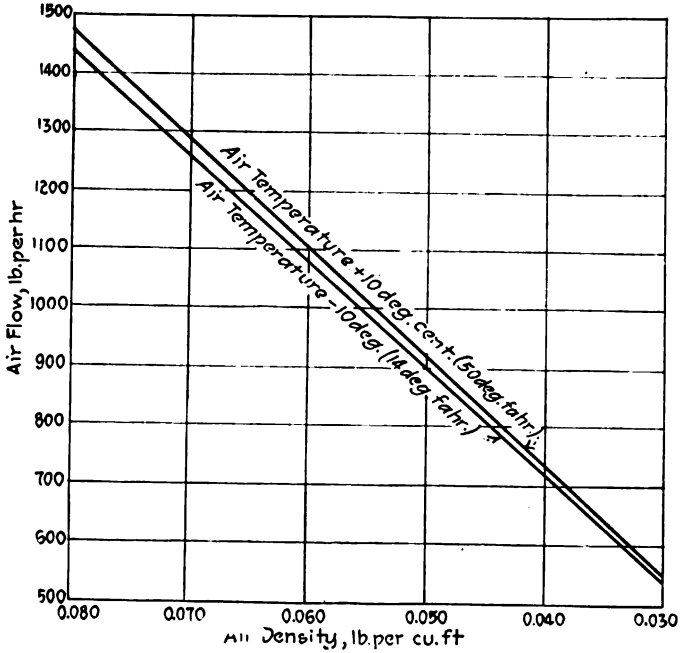

FIG. 2—CURVES SHOWING THE RELATION BETWEEN AIR FLOW AND AIR DENSITY AT DIFFERENT TEMPERATURES

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ratio. Hence, the two curves of Fig. 2 apply to all of the ratios used. The difference arising from the temperature change may cause some surprise. Since the results are plotted against air density or mass per unit volume, the increase in the quantity with an increase in the temperature obviously means a greater volume taken by the engine in a unit time. To discuss the reasons for this increase is beyond the scope of this paper. In passing, however, it may be pointed out that this answers a constantly recurring question; why, if the engine power is dependent upon the weight of charge received, does not a temperature increase cause a decrease in the power which is directly proportional to the resulting decrease in density? An inspection of Fig. 2 gives the answer that the volume of the charge taken by the engine increases with an increase in the temperature. The extent

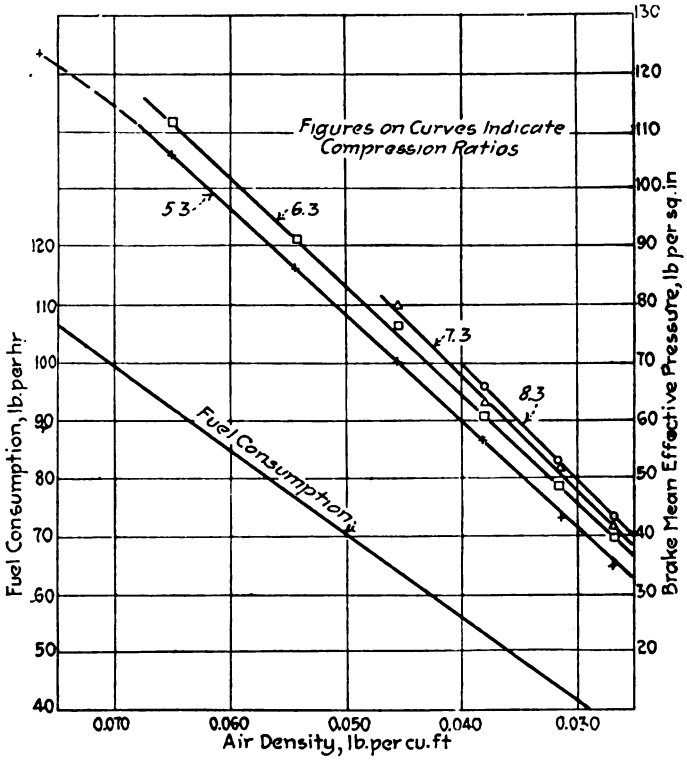

FIG. 3—CURVES OF THE BRAKE MEAN EFFECTIVE PRESSURE DEVELOPED WITH DIFFERENT COMPRESSION-RATIOS AT A GIVEN RATE OF FUEL-CONSUMPTION

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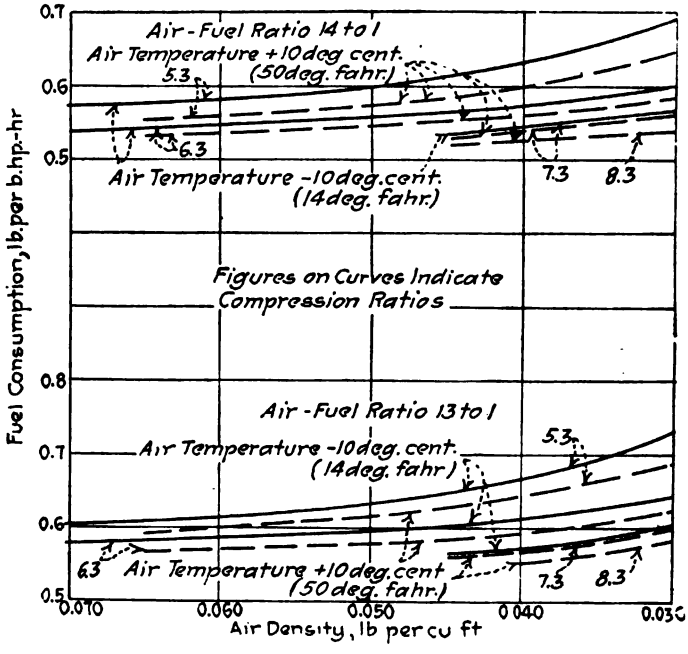

FIG. 4—CURVES OF FUEL-CONSUMPTION FOR DIFFERENT AIR TEMPERATURES AND MIXTURE-RATIOS

to which this volume increase offsets the density decrease determines the actual power-drop.

For a comparison of engine performance on a basis of efficiency and power, the brake mean effective pressure developed with each compression-ratio at a given rate of fuel-consumption was plotted as shown in Fig. 3. These values were taken from curves of the type shown in Fig. 1, the rates of fuel-consumption chosen being such as would be obtained with a carbureter supplying the same mixture-ratio at all altitudes. Since Fig. 2 gives the air flow at all densities, it is merely a matter of division to determine the rate of fuel flow necessary to give any air-fuel ratio. It is of interest that the maximum power for these compression-ratios at all altitudes was obtained with an air-fuel ratio of from 13 to 1 to 14 to 1. Fig. 3 itself needs little explanation. The lower curve gives the fuel-consumption at any density, while the upper curves show the brake mean effective pressure developed from this amount of fuel with each ratio.

The absence of values for the higher compression-

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ratios at the higher densities is due to the preignition that results under such conditions. The final temperature of a gas compressed adiabatically is given by the equation:

$$T_2 = T_1 r^{k-1}$$

where

K = the ratio of the specific heat of the gas at constant pressure to that at constant volume

r = the compression-ratio

T_1 = the absolute temperature at the beginning of compression

T_2 = the absolute temperature at the end of compression

The density of the charge does not appear explicitly in this equation. The key to its influence on the final temperature lies in its relation to the initial temperature

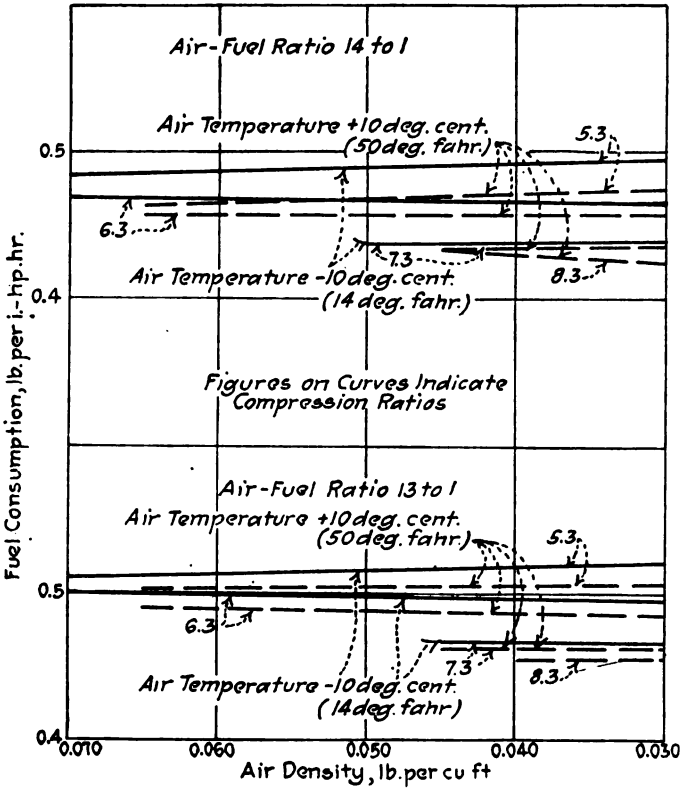

FIG. 5—FUEL-CONSUMPTION IN POUNDS PER INDICATED HORSEPOWER AT DIFFERENT COMPRESSION AND AIR-FUEL RATIOS

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T_1. This temperature depends upon the heat supplied to the entering charge by the hot walls of the combustion-chamber. The temperature of these walls and hence the amount of heat supplied by them is governed by the power developed. Since the power developed depends upon the density, the relation of the density to the temperature at the end of the compression is seen to be fundamental, although indirect. It must not be inferred that engine operation is impossible at these higher densities. Some fuels are known to give satisfactory operation under these conditions. The engine can be designed so as to render unnecessary development of full-load power at the lower altitudes. It seemed logical to determine first the gain that would result from increasing the compression and then to judge whether or not this gain would justify the change in fuel or the modifications in engine design necessary to employ such a ratio satisfactorily.

Fig. 4 summarizes the results showing the fuel-consumption in pounds per brake-horsepower-hour for two air temperatures and two mixture-ratios. The larger consumption at the greater altitudes is due to the higher percentage that the friction power there bears to the brake power. This is borne out by Fig. 5, where the fuel-consumption is plotted in pounds per indicated-horsepower-hour. These curves suggest that the efficiency of combustion is influenced but little by a change in the density so long as the temperature is maintained constant. Temperature, on the other hand, appears to have a considerable effect. It is probable that an explanation of this will be furnished by a more complete analysis of these results. That the gain varies so greatly with the different compression-ratios makes any explanation on the grounds of a change in distribution highly improbable.

As a matter of interest, average indicated thermal efficiencies and the corresponding air standard efficiencies have been tabulated and are given in Table 1. It will be recalled that the air standard efficiency for the Otto cycle is given by the expression

$$E = 1 - (1 \div r)^{k-1}$$

where

E = the air standard efficiency

K = the specific heat at constant pressure divided by the specific heat at constant volume or 1.4 for air

r = the compression-ratio

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TABLE 1—RELATION BETWEEN INDICATED THERMAL AND AIR STANDARD EFFICIENCIES

Compression-Ratio	Air-Fuel Ratio	Temperature, deg. cent.	Temperature, deg. fahr.	Indicated Thermal Efficiency, per cent	Air Standard Efficiency, per cent	Indicated Thermal Efficiency in Terms of Air Standard Efficiency, per cent
5.3	13 to 1	+10	50	26.6	48.8	54.5
6.3	13 to 1	+10	50	27.5	52.2	52.6
7.3	13 to 1	+10	50	29.0	54.9	52.8
8.3	13 to 1	+10	50	29.5	57.1	51.8
5.3	14 to 1	+10	50	28.7	48.8	58.8
6.3	14 to 1	+10	50	29.4	52.2	56.3
7.3	14 to 1	+10	50	31.0	54.9	56.5
8.3	14 to 1	+10	50	31.5	57.1	55.2
5.3	13 to 1	—10	14	26.0	48.8	53.3
6.3	13 to 1	—10	14	27.0	52.2	51.7
7.3	13 to 1	—10	14	28.8	54.9	52.4
5.3	14 to 1	—10	14	27.6	48.8	56.5
6.3	14 to 1	—10	14	28.9	52.2	55.5
7.3	14 to 1	—10	14	30.6	54.9	55.8

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Fig. 6 presents the brake thermal efficiencies as percentages of the efficiency of the 5.3 compression-ratio. It brings out very clearly that the gain ensuing from the employment of the higher ratios increases with an increase in the altitude. This latter effect is due solely to the increase in power and the resulting smaller ratio of friction to brake power. Hence, the same condition would result from supercharging or from any other method of efficiently increasing the power developed. An example will illustrate the point. Assume a brake horsepower of 50, a friction horsepower of 20 and an indicated horsepower of 70. With a fuel consumption of 0.45 lb. per i.hp-hr. 31.5 lb. would be used in 1 hr. This makes the consumption in pounds per brake-horsepower-hour 31.5 ÷ 50 or 0.63 lb. If the engine be furnished an increase in the charge weight sufficient for it to develop 80 i.hp. the fuel used will be 36 lb. per hr. Such an in-

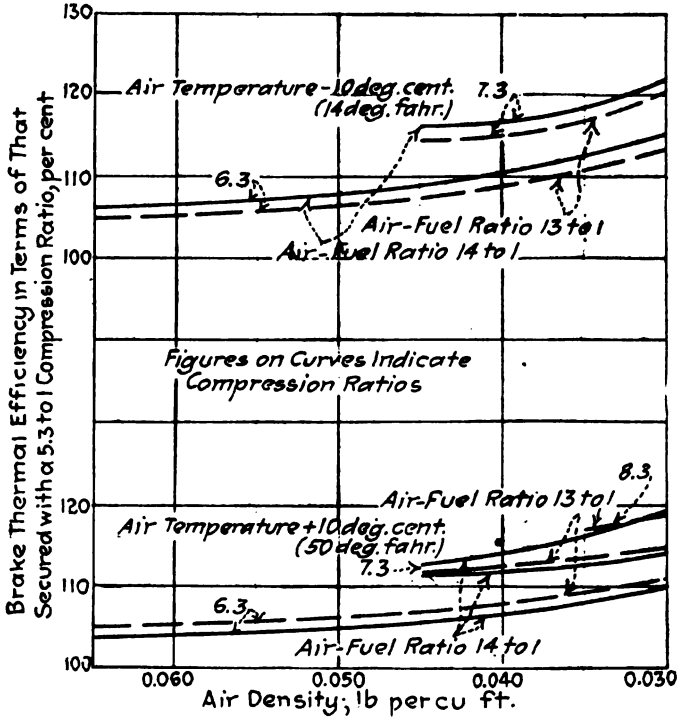

FIG. 6—BRAKE THERMAL EFFICIENCIES FOR DIFFERENT AIR TEMPERATURES AND COMPRESSION-RATIOS OF 6.3 TO 1 AND 7.3 TO 1 EXPRESSED AS PERCENTAGES OF THE EFFICIENCY OBTAINED WITH A RATIO OF 5.3 TO 1

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crease will not materially change the friction and the brake power will become 80 — 20 or 60 hp. The fuel-consumption now becomes 36÷60 or 0.60 lb. per b.hp-hr., a 5-per cent decrease. With a supercharger furnishing the increased charge, the efficiency of the supercharging device would enter the calculation, making the net gain less. If, on the other hand, the increased power were obtained by an increase in the compression-ratio, the gain would be more because there would be a lower fuel-consumption in pounds per indicated-horsepower-hour with the higher ratio. In other words, with an increase in the compression-ratio there is a gain in the indicated efficiency that is peculiar to this method of increasing power and, in addition, a gain in the brake efficiency that is common to all methods of increasing power.

TORSIONAL STRENGTH OF MULTIPLE-SPLINED SHAFTS

By C W Spicer[1]

The results of some tests recently completed are presented. No attempt is made to develop the theory involved. It is intended to describe only the actual tests, the conditions under which they were carried out and the results obtained.

Superficially, it would seem obvious that the torsional strength of a multiple-splined shaft is greater than that of a full round shaft having a diameter equal to the small diameter of the splined shaft. Data on this and related questions were sought experimentally. A series of tests was run on 15 carefully machined shafts. The dimensions shown are the actual ones of the test-pieces, there not being more than 0.0005-in. variation in any shaft from the diameters shown. Heat-treating was very carefully carried out, and each specimen carefully checked by Brinell instrument on the ends and by scleroscope throughout the length. The Brinell numbers were all between 220 and 235, and the extremes of scleroscope hardness were 38 and 43. The testing machine and a composite curve of test results are shown.

Various theories have been advanced regarding the torsional strength of multiple-splined shafts. So far as I am aware there are very few available published data

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on the subject. The results of some recently completed tests will, therefore, be of interest. In preparing these data it is intended to describe only the actual tests, the conditions under which they were carried out and the results obtained. No attempt will be made to develop the theory involved.

Superficially, it would seem obvious that the torsional strength of a multiple-splined shaft would probably be greater than that of a full round shaft having a diameter equal to the small diameter of the splined shaft. Data on this and related questions were sought experimentally.

A series of tests was run on 15 carefully machined shafts, as indicated in Fig. 1. The dimensions shown are the actual ones of the test-pieces, there being not more than 0.0005-in. variation in any shaft from the diameters shown. Heat-treating was very carefully carried out, and each specimen carefully checked by Brinell instrument on the ends and by scleroscope throughout the length. The Brinell numbers were all between 220 and 235, and the extremes of scleroscope hardness were 38 and 43. It was at first intended that the small diameter of shafts Nos. 1 to 5 should agree exactly with the small diameter of shafts Nos. 6 to 10. It was decided after the heat-treating had been done to avoid any straightening operations and, therefore, the small diameter of shafts Nos. 1 to 5 was reduced to a size that would clean up the most badly warped shaft by grinding. This also accounts for the large diameter of shafts Nos. 6 to 10 being below the 1⅝-in. nominal diameter. However, none of these details materially affected the results, as will be seen later.

It will be noticed that the small diameter of shafts Nos. 11 to 15 lies between the large and the small diameters of shafts Nos. 6 to 10 in approximately the relation shown in the lower left corner of Fig. 1. This diameter represents a shaft which, according to one authority, is hypothetically equivalent to the splined shaft in torsional strength. That it is far from equivalent will be seen later.

Fig. 2 is a photograph of the 15 specimens ready for the test and Fig. 3 shows the Olsen torsion testing-machine with one of the specimens ready for testing. All readings from which the curves shown in Fig. 4 were prepared were taken by the Olsen troptometer attachment, which is plainly shown.

The results of the individual tests of the five speci-

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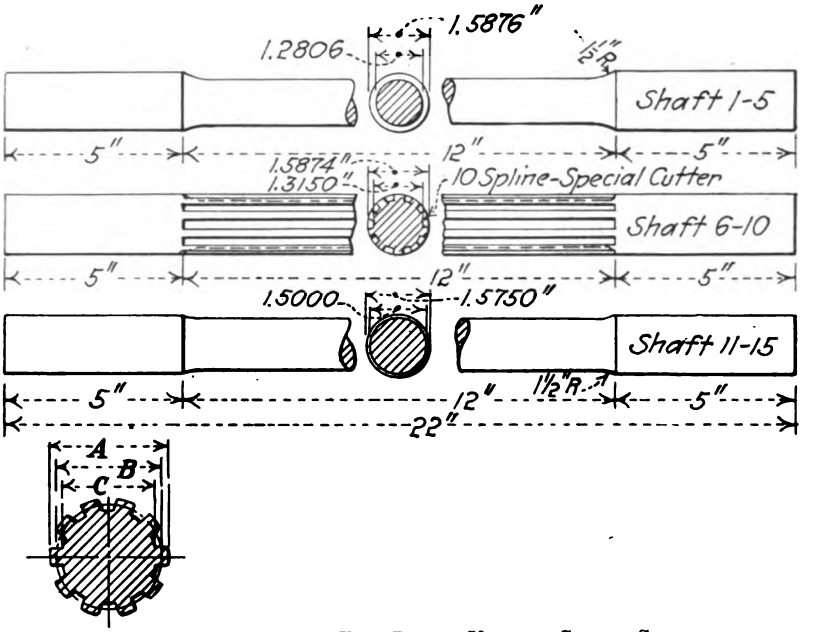

FIG. 1—DIMENSIONS OF TEST-PIECES USED IN SPLINE SHAFT TORSION TEST

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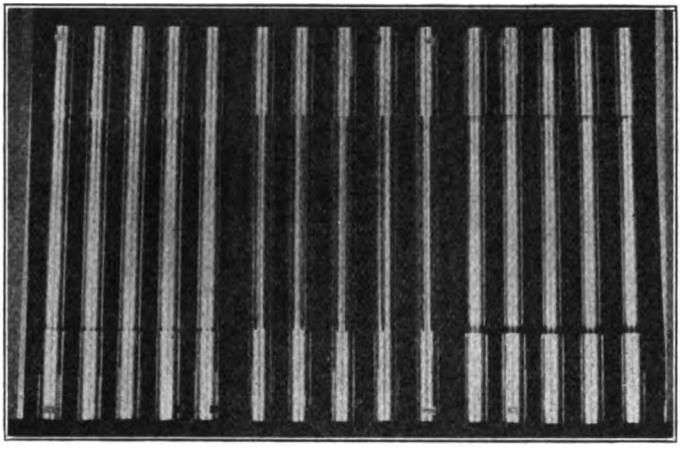

FIG. 2—THE 15 SHAFTS WHICH WERE TESTED

mens of each group were very uniform and it therefore does not seem necessary to give the detail curves of each specimen. The curves shown in Fig. 4 represent the average of the five shafts in each group, and are self-explanatory. Curve *a* is the plotted average of shafts Nos. 1 to 5. Curve *b* is curve *a* corrected for a diameter

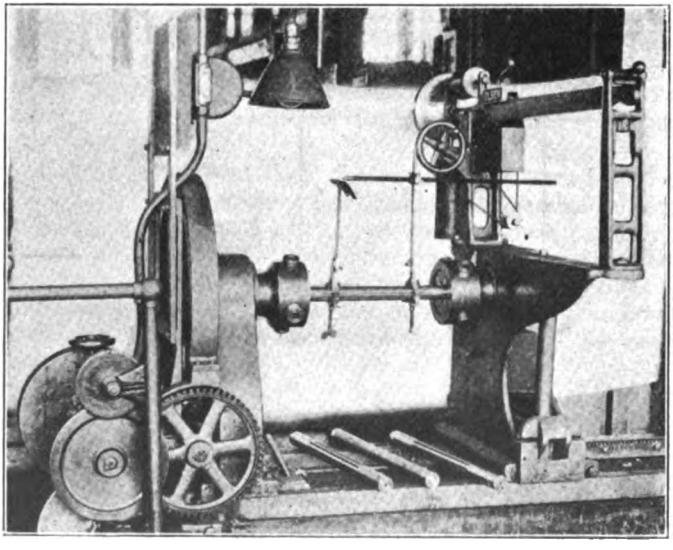

FIG. 3—THE TESTING MACHINE EMPLOYED

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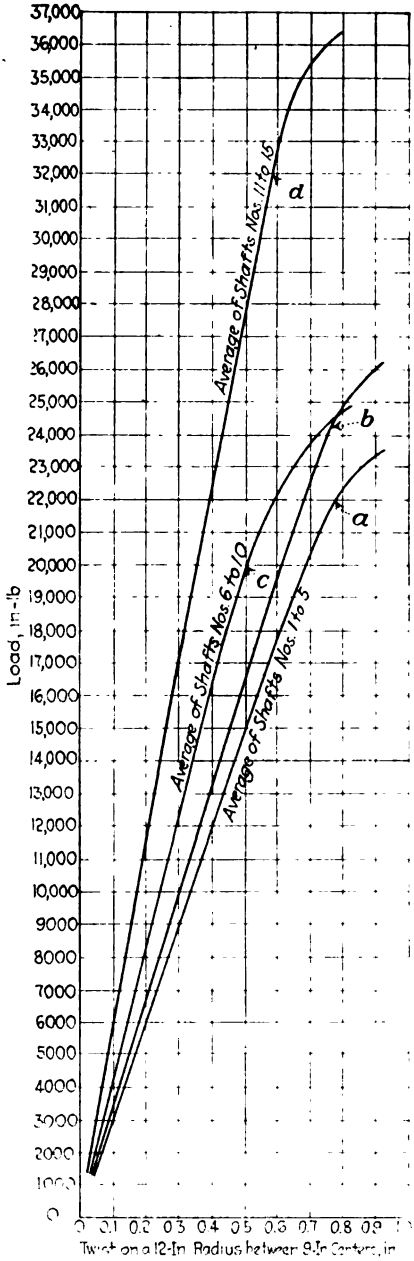

Fig. 4—Composite Curve of Test Results

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equal to the small diameter of shafts Nos. 6 to 10 for convenience in comparing with curve *c* which is the average of shafts Nos. 6 to 10; and curve *d* is the average of shafts Nos. 11 to 15.

The position of the letters *a*, *c* and *d* also indicate the location of the so-called Johnson elastic-limit; that is, the point at which the unit increment of deflection per unit of load increase is 50 per cent greater than at the beginning.

Comparing curves *b* and *c* it will be readily seen that a splined shaft of the dimensions given has a torsional elastic-limit of approximately 18 per cent less than a full round shaft of a diameter equal to the small diameter of the splined shaft although the deflection for any given load below the elastic-limit is greater in the smaller shaft. The elastic-limit of the hypothetically equivalent shaft is very much higher.

For the convenience of those who have not studied torsional tests and strain diagrams recently, attention may be called to the fact that the torsion-test curve of ductile material is very different in form from the corresponding tension-test curve for the reason that the intensity of stress on any small unit of material at any instant varies with its distance from the axis of the test-piece. Consequently, when the outermost fibers of the specimen have reached their elastic-limit, the fibers near the axis of the section are still only slightly stressed. This fact undoubtedly accounts for the comparatively low elastic-limit indicated at *c*, the outer layer of material having been greatly weakened by cutting the splines. [The discussion of this paper is printed on page 90.]

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INTAKE FLOW IN MANIFOLDS AND CYLINDERS

By P S Tice[1]

The paper describes the results obtained from making visual observations of the paths followed by the several portions of the air-stream. One of the passages being considered was half-sectioned in a plane about which the passage was symmetrical; that is, a plane containing the axes of the several parts of the passage. A flat glass plate was then cemented on to complete the half-passage. With the outlet end of such a passage connected to an engine intake, any sort of flow encountered in engine practice can be reproduced. By introducing gasoline with the entering air, a tracery of fine sharply defined lines on the glass is produced and this was photographed, as is described in detail. Varied shapes of passages were studied in this manner. These are illustrated and the variations in the results under differing conditions are discussed.

Several months ago, in the execution of a certain piece of work, it became evident that the air-flows in the passages generally employed were not nearly so simple and orderly as our small knowledge of such matters had led us to expect. There was every evidence of the existence of eddies, whirls and impacts of considerable magnitude at various points in the passage. After experimenting a bit, it was decided to stop guessing, and devise a means of making visual observations of the paths followed by the several portions of the air stream.

One of the passages being considered was half-sectioned in a plane about which the passage was symmetrical; that is, a plane containing the axes of the several parts of the passage. This method of making the cut causes the least disturbance of the flow lines in the sectioned member, as compared with those in the complete passage. A flat glass plate was then cemented on to complete the half-passage. With the outlet end of such a passage connected to an engine intake, any sort of flow encountered in engine practice can be reproduced. It then only remained to introduce a comparatively non-volatile liquid that readily wets glass, such as gasoline, with the entering air, to cause a tracery of fine sharply defined lines

[1] M.S.A.E.—Engineer in charge of the carbureter division, Stewart-Warner Speedometer Corporation, Chicago.

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on the glass. These follow the air-flow lines faithfully and permit one to make valuable studies of passage flows. The application of the information obtained with this method of observation has proved that the tracery seen on the glass sufficiently indicates the flow lines followed in the middle plane of the complete full-section passage.

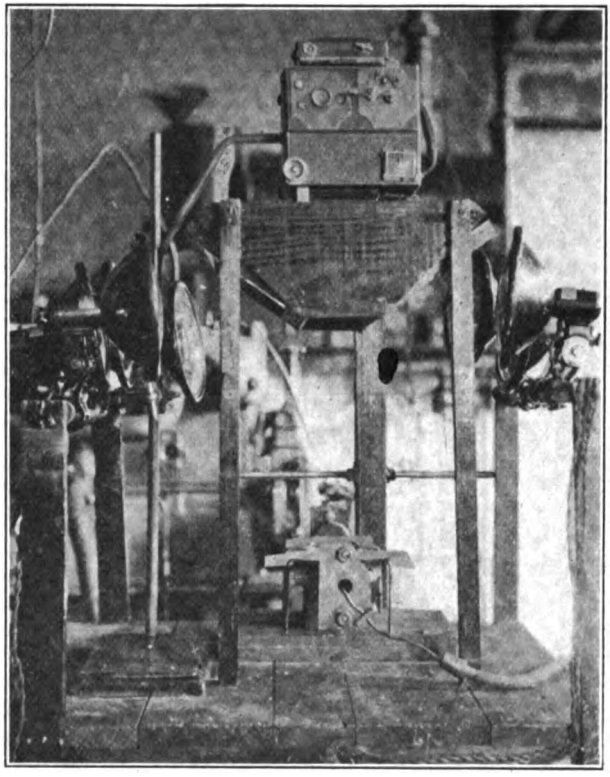

FIG. 1—THE ARRANGEMENT OF THE CAMERA WHICH WAS USED TO MAKE THE PHOTOGRAPHS OF MANIFOLD CONDITIONS

Following the completion of the work for which the set-up was made one of my assistants suggested that we apply the same method of observation to typical intake-manifolds and cylinder combustion-chambers. The illustrations in the paper represent a portion of these latter observations.

Fig. 1 shows the photographic set-up used for recording purposes. A 3¼ x 4¼-in. Graflex camera is sup-

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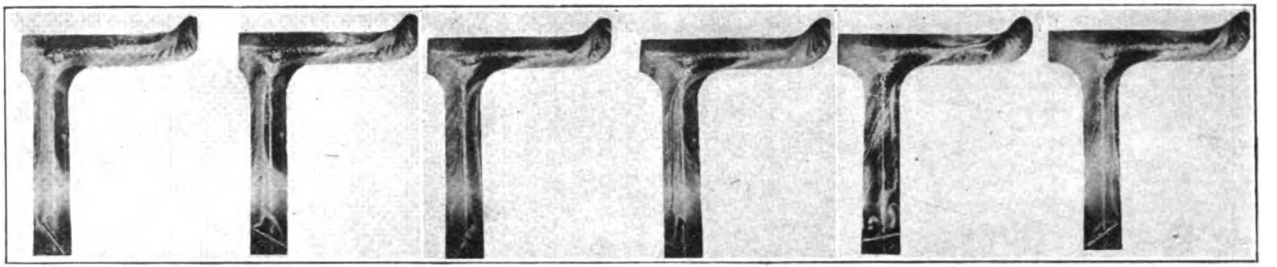

FIG. 2—PHOTOGRAPH OF A MANIFOLD HAVING A COMPARATIV ELY LONG RISER SHOWING HOW THE FLOW IN THE RISER IS CHANGED BY VARYING THE ANGULAR POSITION OF THE THROTTLE

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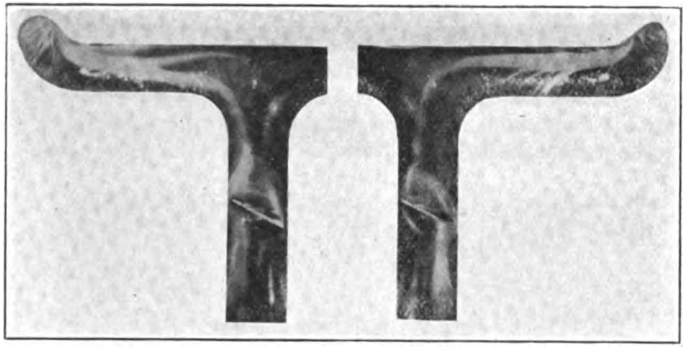

FIG. 3—CONDITIONS EXISTING IN THE MANIFOLD WITH THE THROTTLE OPEN SLIGHTLY

ported to point directly down upon the glass wall of the half-passage. A framework supports two rectangular mirrors which are used to reflect the light from a group of spotlights, in lines nearly normal to the glass on which the tracery appears. A black paper mask, cut to the outline of the passage, keeps the images of the lamps off the camera screen. The reflection and refraction of the light as the fine liquid streams on the glass, cause their positions to be defined sharply on the camera screen. It has been found that, while complete detail is obtained

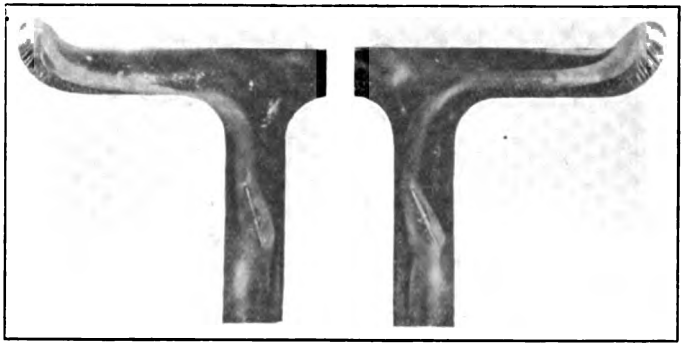

FIG. 4—MANIFOLD CONDITIONS WITH THE THROTTLE APPROXIMATELY HALF-OPEN

with intense illumination and short exposure, the best general purpose records result from an exposure of from 5 to 10 sec., with reduced illumination. This latter method gives a flatter, softer negative, but one which

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shows the general and more important flow lines to better advantage.

Fig. 2 illustrates what happens in a manifold with a comparatively long riser. In this group the throttle is taken through a half-revolution by considerable increments. The significant revelation here is the small effect upon conditions in the horizontal branch, resulting

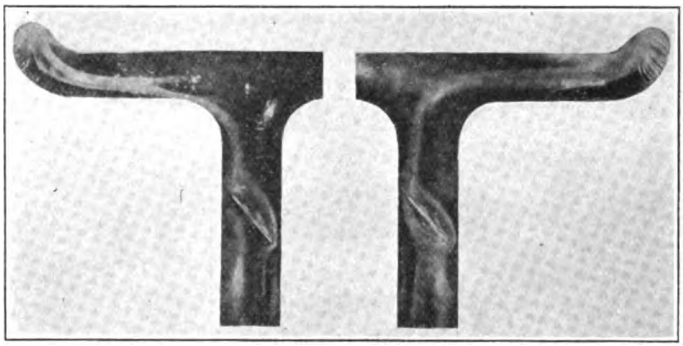

FIG. 5—OPENING THE THROTTLE STILL FARTHER HAS NOT PRODUCED ANY MATERIAL CHANGE IN THE MANIFOLD CONDITIONS

from a complete reversal of the throttle angular position, even though such change materially alters the flow in the riser. The whirling set up in the stream as it enters the

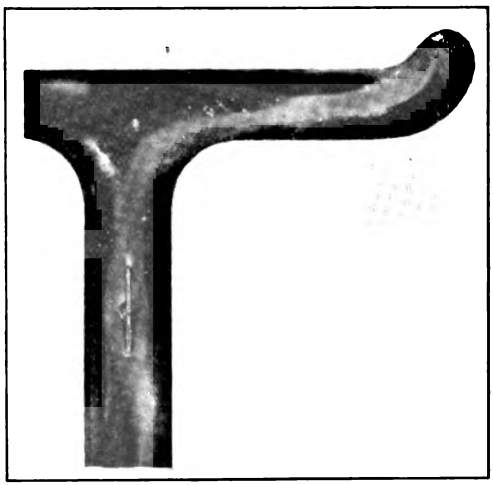

FIG. 6—A WIDE-OPEN THROTTLE RESULTING IN IDEAL FLOWS IN THE TWO INTAKE BRANCHES

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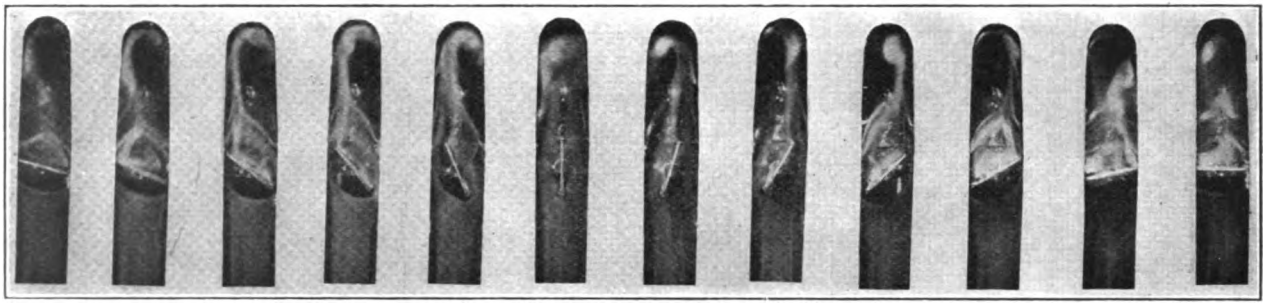

FIG. 7—PHOTOGRAPHS TAKEN WHILE THE THROTTLE WAS ROTATING THROUGH 180 DEG.

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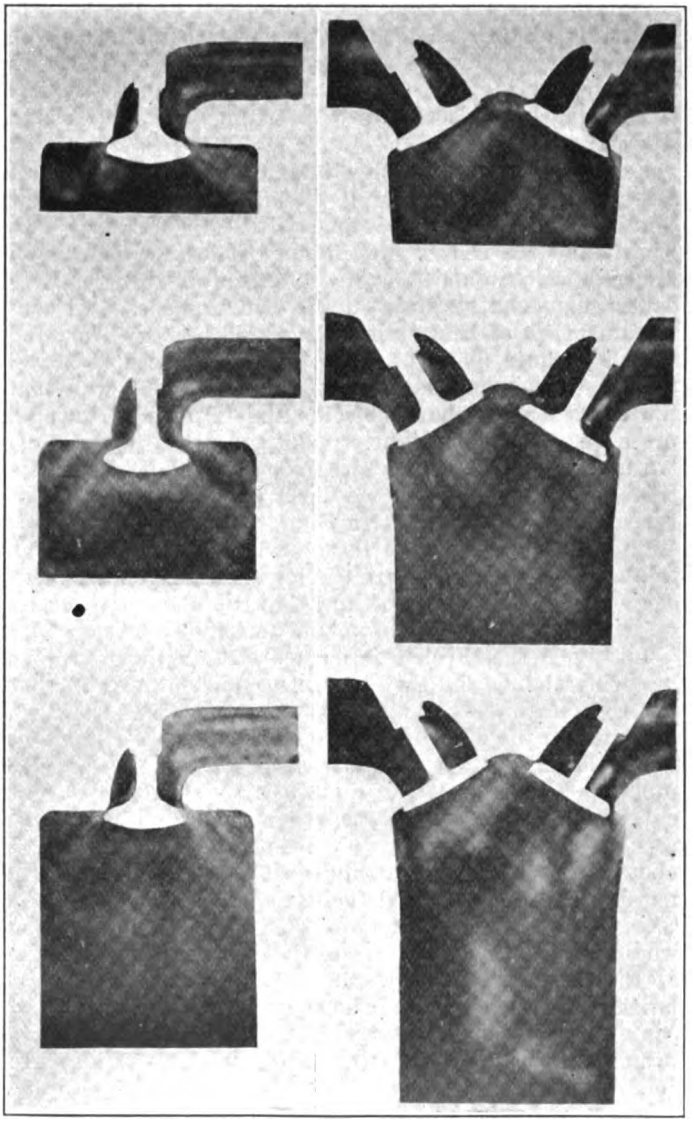

FIG. 8—INTAKE FLOW IN TWO TYPICAL VALVE-IN-THE-HEAD CYLINDERS

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outlet bend should be noticed and also that the major portion of the fuel hugs the lower wall of the branch, beginning at the tee itself. This latter point, it will be remembered, was well shown by W. S. James at the 1920 Summer Meeting. The pictures in this group are typical of the photographic results with strong illumination and short exposure.

Less intense illumination and an exposure of about 5 sec. were used in making the next set of records of conditions in a typical intake with a short riser. In Fig. 3 and the others immediately following, the views are grouped to show the direct effects of throttle-valve deflection upon the flows in the two branches. In considering each of these views, it should be borne in mind that the liquid filaments lie in and are forced to travel toward the low-pressure regions, in the same way that the earth's atmosphere flows to the regions of lowered pressure. Thus, the light streaks and areas in the illustration represent the low-pressure or high-velocity portions of the stream, and the dark places those regions of relatively high pressure. In Fig. 4 the throttle is opened slightly farther, and the reason why liquid distribution to the branches is sometimes imperfect is shown very clearly by the presence of liquid in the non-active outlet of the tee in one case and not in the other.

In Fig. 5 the throttle is opened still farther, with no material change in the general condition. A further cause of unequal distribution among cylinders is shown to reside in the whirling set up in the bends forming the manifold outlets. It is seen that in the two ends of the pipe the concentrations of liquid occupy somewhat different positions. Furthermore, when the whirling charge reaches the usual siamesed valve-ports, the chances are about 20 to 1 that one cylinder of the pair will receive more of this concentrated fuel-stream than the other. It seems that a useful control of this phase of distribution would result, in any one case, from altering the lengths of the curved portions at the manifold outlets. Fig. 6 finishes this group, and shows open-throttle which, of course, results in perfectly identical flows in the two branches, provided the carbureter is shaped and mounted so as to permit it.

Fig. 7 shows the same form of manifold as that just preceding, but sectioned through the riser in a plane at right angles to the outlets of the tee. At the top of each view, one is looking directly into a branch. Also, the throttle spindle lies in the same plane as the branches.

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This is an effective arrangement for insuring equality of distribution to the tee outlets, but it also results in an energetic whirling or rotation of the whole stream, beginning at the tee, and persisting throughout the whole remaining length of the passage.

Here the throttle is rotated through 180 deg., to show completely its deflecting action. In making these records, the liquid was introduced in a thin film traveling along the surface of the glass; while in the others it was merely sprayed into the air-stream. This was done to bring out more clearly the behavior of the air-stream at the throttle-valve. It is interesting to note how coming events cast their shadows before them at the upstream side of the throttle. At open-throttle the entering edge of the 1/16-in. thick valve is enveloped in a region of high pressure possessing a curiously alluring but apparently empty form; while at small angles from

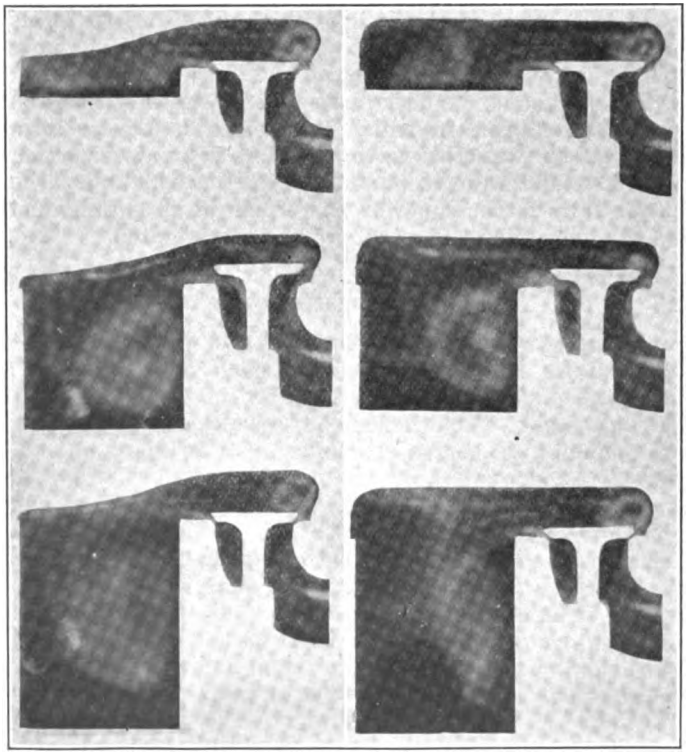

FIG. 9—INTAKE FLOW IN TWO FORMS OF L-HEAD COMBUSTION SPACES

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the open position, this region has sections suggesting a thick airfoil. The flow, with respect to its rotational direction in the branches, is very unstable at open-throttle, first whirling in one direction and then the other, resulting, in this photographic record, in what appears to be a symmetrical figure. These exposures had a duration of from 9 to 10 sec.

In Fig. 8 we have intake flow in two typical valve-in-head cylinders. The three views of each cylinder are intended to represent the beginning, the middle and the end of the suction stroke. Note particularly the forms and locations of the whirls at small clearances, and how they die out, so far as any concerted internal motion in the mass is concerned, as the piston is moved out. From this showing, it seems reasonable to suppose that this heterogeneous motion would not amount to much as a useful turbulence at the end of the compression stroke.

In Fig. 9 are corresponding views made in two forms of L-head combustion spaces. The enlarged and more persistent whorls, as compared with the valve-in-head cylinders, should be noticed as well as the fact that the combustion space in which the height is non-uniform is greatest over the valves, causes a greater portion of the total charge to participate in the whirling. The latter form is the superior performer in an engine, and an exaggeration of it might well be investigated.

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AERIAL TRANSPORTATION

By Ralph H Upson

The author gives an outline of the fundamentals and divides the subject into a discussion of what aerial transportation facilities we have at present and what should be considered for the future, stating that the inventors must determine how far they can go in providing equipment.

The first question regarding new equipment is, "Will it work?" The next, "Is it safe?" Safety is described as being purely relative, the statement being made that there is no such thing as absolute safety. There is no need to expect danger. We must have both speed and safety and making aerial equipment safe is well worthwhile, no matter at what expense of money and effort.

As to whether commercial aviation can be made to pay, economically and so far as society as a whole is concerned, this is a relative question depending upon the length of haul and the cost per mile.

Charts are shown and methods of obtaining basic costs described, together with formulas and coefficients so obtained. These are worked out for both airplanes and airships. Other charts giving the yearly operating costs of airships, their capital expense and cost curves, and the size of airships required for given cruising radii are shown and explained. The speed and cost data for cargo of varying time-value carried over various distances, and the cost of freight transportation, are presented in additional charts.

The economics of a business is usually worked out after the business in question has become well established. The success of the railroad or the automobile has been necessary to encourage the formation of college courses for the study of them, which is extremely valuable, although it comes too late to be of much service in the organization of the original plan. I am trying to outline in advance some of the factors in the fundamental economics of air transportation which must be recognized even in its original plan and conception, especially in regard to the airship, which requires such a large outlay of capital at the start if we are to expect much success. The extent to which investors will place money in plans of this kind, the extent to which communities will develop

[1]M.S.A.E.—Consulting engineer, with Alexander Klemin and Associates, New York City

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landing-fields and the extent to which Congress can be prevailed upon to furnish what aid may be necessary all depend upon the whole subject working out as a real economic factor.

We have three recognized forms of transportation worth mentioning at present; railroad, steamship and motor truck. Of these I would call the railroad and steamship primary and the motor truck secondary, the last named being used for more special purposes. As to the new forms of transportation, the airplane and the airship, in the last analysis it must be left to the investors to decide how far to go. Three questions are typical of the average investor in this connection, and they are worth noting at the start. In considering a new transportation vehicle the first question is, "Will it work?" The attitude expressed in this question is now nearly outgrown. It was formerly the one formula for inventors and investors alike, but the matter of whether an invention will "work" is left entirely now to the men who have studied the subject and proved that they know how to make their inventions work. The next question is somewhat more imminent. We are not yet past the stage where we ask, "Is it safe?" Many of us base most of our calculations on that point. But I am sure that this matter also soon will be left in the hands of men who have proved that they know how to make air-travel safe, with much the same confidence. But, because it is a point often raised at present, it is well to take it into consideration. Safety is relative. There is no such thing as absolute safety; but the relativity of safety must be applied in the right direction. There are certain apologists who argue that we should expect danger in aircraft, that we cannot get something for nothing, that we are getting extra speed and that we should expect to take somewhat more risk. I distinctly disagree with any such sentiment. In fact, all reasonably consistent analysis seems to indicate exactly the contrary, that the more speed we have, the more important the matter of safety is. This will be clear, as applied to passengers, from just one consideration. If the time of a business man is of the utmost value and he is willing to pay the fare which will be required for air-travel, to pay extra for increased speed, he also will value his safety that much the more. He will be unwilling to use a transportation vehicle, no matter how fast, if he must risk his life in the attempt. So, I insist that in aviation work it

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is not a matter of sacrificing safety to get speed; there must always be speed *and* safety. As a fundamental fact, if any transportation system is worthwhile, it is worth whatever trouble and expense may be necessary to make it safe. There are so many different ways of accomplishing safety that there is absolutely no excuse for failure to make vehicles safe. It is simply a matter of proper design; that is, suitable design, and organizing for the purpose. So, for present purposes, we will assume that safety is a part of the general economics of the subject; in other words, we will take it into account in our cost figures by including the cost of safe design and organization.

The third fundamental question of investors, which we encounter more and more frequently and is the only logical basis for development is, "Will it pay?" I do not refer here to any individual investor. We can take it for granted that any man who puts his money into a business hopes to get some personal profit out of it. I refer here to the broader question of whether an enterprise will pay generally, economically, for society as a whole; after all, that is the only sure foundation upon which we can establish any big industry of this kind. This matter of profit involves some factors that should be of extreme interest to anyone interested in the subject or, indeed, to anyone who is interested in life itself, because transportation is a very intimate factor in modern life.

Fundamental Factors

The fundamental factors are length of haul, mileage cost, cargo or passenger capacity and the amount of business it is possible to obtain in any one class. The length of haul and mileage cost go pretty much together. I am working out the transportation cost per 1000 lb. per 1000 miles for different lengths of haul. The standpoint that I am taking for this is not passengers, fundamentally, but freight. I realize that this is a somewhat novel procedure, but I feel that it is the more fundamental standpoint, and it can be worked out readily later in terms of passengers. The first thing to do is to determine on certain basic costs; that is, to take a certain typical more-or-less familiar case, the costs of which we know, and then consider how the different items can be classified with respect to their sources; especially, to determine how they vary for different other conditions, particularly for changes in speed and size.

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TABLE 1—BASIS FOR AIRPLANE COSTS,[2] CAPITAL ACCOUNT

Items	Cost
One Airplane, Including Powerplant, at $4 per lb.	$30,000
One-Half of Oversize Hangar Space	15,000
Land, One-Eighth of 80 Acres	30,000
Shops, etc., One-Eighth of Total Cost	20,000
Offices and Miscellaneous, One-Sixteenth of Total Cost	20,000
Working Capital and Reserve	100,000
Total	$215,000

[2]For one 800-hp. all-metal airplane of 15,000-lb. gross lift; maximum speed, 105 m.p.h.; average landing speed, 60 m.p.h. Costs include a proportional share of all equipment, assuming an average of eight planes on the station at a time.

Table 1 shows the capital account for the base airplane-line. This is simply an assumed layout for an airplane line, based on certain arbitrary assumptions. The only claim I make for the figures is that they are generally comparative for the different transportation vehicles. I have taken as authorities the most optimistic of the experts in their particular lines. It should be noted that the costs are not to be taken as proper for figuring actual rates, profits and the like; in that case we must figure high. In this case I am figuring rather low to obtain comparative figures all the way through. On the capital account, for example, I have charged uniformly 8 per cent interest. Table 2 is the yearly operating account for airplanes under certain assumptions. Some engineers may say that it is too good and that this cannot be achieved with the planes we have available at present. I know it cannot be done with made-over war-planes and, if one has other ideas of what can or cannot be done, by all means let him substitute his own figures, if preferred.

Table 3 shows the general method by which the comparisons are worked out. It comprises a series of columns, headed by the quantity which governs the variation of each of the items. Column 2, for example, comprises all costs which depend only upon the carrying capacity of the vehicle. Column 3 depends upon the powerplant, including fuel. Column 4 depends upon the length of route, which is another way of saying that its costs are those due to the landing and starting of the plane. Column 5 comprises certain expenses due to the handling of the cargo itself, which are not at all dependent upon the capacity of the plane, but upon the number of pounds

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TABLE 2—YEARLY OPERATING COSTS OF AIRPLANES[3]

Items		Percentage	Cost
Interest on Investment		8	$17,200
Insurance	Airplane	20	6,000
	Terminal	1	800
Depreciation	Airplane Powerplant Renewals	..	70,000
	Remainder of Airplane	20	3,500
	Terminal	5	2,500
Maintenance	Airplane Powerplant	..	20,000
	Remainder of Airplane	..	10,000
	Terminal	..	3,000
Operating Personnel	Airplane Powerplant	..	15,000
	Remainder of Airplane	..	10 000
	Terminal	..	10,000
Miscellaneous Overhead		..	35,000
Gasoline and Oil, average 40 cents per gal.			77,000
Total per year			$280,000

$$\frac{280{,}000 \times 1000 \times 1000}{2920\ (103 - 11.5) \times 0.49 \times 15{,}000}$$

$$= \$143 \text{ per 1000 lb. per 1000 miles.}$$

$$\frac{800 \times 2920 \times 0.75 \times 0.60 \times 0.40}{6}$$

$$= \$70{,}000 = \text{Theoretical cost of gasoline.}$$

[3]For an 800-hp. airplane on a steady route of 200 miles, flying one-third of the total time; average air-speed, 103 m.p.h. at three-quarters of full power; altitude, 7000 to 9000 ft.; four regular trips per day.

TABLE 3—AIRPLANE UNIT COSTS[4]

Items	Item Varies As $\frac{1}{C(v-11.5)}$	$\frac{P}{C(v-11.5)}$	$\frac{1}{Cs}$	$\frac{1}{s}$	Total
Col. 1	Col. 2 Per year	Col. 3 Per year	Col. 4 Per year	Col. 5 Per year	Col. 6
Interest	$13,200	$4,000			$17,200
Insurance	4,000	2,800			6,800
Depreciation	4,000	70,000	$2,000		76,000
Maintenance	12,000	20,000	1,000		33 000
Personnel	10,000	15,000	500	$9,500	35 000
Overhead	15,000	5,000	5,000	10,000	35,000
Fuel		71,500	5,500		77,000
Total	$58,200	$188,300	$14,000	$19,500	$280,000
Coefficient	1,330	20,400	700	2,000	
Unit Cost	$30.00	$95.90	$7.10	$10.00	$143.00

[4]Cost, in terms of dollars per 1000 lb. per 1000 miles, equals $(24{,}000 \div [C\ (v - 11.5)])\ (6.5 + P) + 700/Cs + 2000/s$.

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handled, whether distributed between one or a dozen planes. After these costs are summed up in Column 6, the coefficient of variation is worked out for each column and then the unit cost per million pound-miles and the results are combined finally in the general working formula shown.

Tables 4 and 5 show the same line-up for airships. One interesting fact is brought out in this specimen case; the airship capital account is nearly 10 times as much as the airplane account, but the operating cost is only about double, for a carrying capacity vastly greater. The classification of the costs is worked out in a similar manner as for airplanes, except that another variable, size, has been taken into account also.

Fig. 1 shows the general effect of variation in size for a constant speed of 70 m.p.h. The long and tedious work of calculating the effect of size on the carrying capacity, which of course is vital in connection with the unit cost, is omitted. Fig. 1 shows the great effect of size. The scale of volume is at the bottom. Vertically, we have the percentage of cargo as compared to gross displacement, and also the cost of haulage in terms of dollars per 1000 pounds per 1000 miles. The heavy curves at the top are the carrying capacities for routes of different length, running from zero to 8000 miles. It is evident that the size for the largest percentage of carry-

TABLE 4—BASIS FOR AIRSHIP COSTS,[5] CAPITAL ACCOUNT

Items		Cost
One Rigid Airship of 2,000,000-cu. ft. capacity; maximum speed, 80 m.p.h.	Powerplant, at $5 per lb.	$100.000
	Remainder of Airship at $8 per lb.	500,000
One-Half of Oversize Hangar Space, or One Single Hangar		600,000
One Mooring Tower and Equipment		50,000
Land at One Terminal, One-Half of 160 Acres, ½ Mile Square		200,000
One-Half of Cost of Gas Plant, Powerhouse and Airships		100,000
Offices and Miscellaneous, One-Quarter of Total Cost		100,000
Working Capital and Reserve		600,000
Total		$2,250,000

[5] For one airship and its own share of equipment, assuming two airships handled per day at each terminal.

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TABLE 5—YEARLY OPERATING COSTS OF AIRSHIPS[6]

Items		Percentage	Cost
Interest on Investment,		8	$180,000
Insurance	Airship	10	70,000
	Terminal	1 to 2	17,000
Depreciation	Airship Powerplant Renewals	..	180,000
	Remainder of Airship	30	150,000
	Terminal	5	48,000
Maintenance	Airship Powerplant, Overhauls, etc.	..	50,000
	Remainder of Airship, Current Repairs		30,000
	Terminal, Current Repairs	..	20,000
Operating Personnel	Airship Powerplant	..	40,000
	Remainder of Airship	..	30,000
	Terminal	..	120,000
Miscellaneous Overhead		..	150,000
Gasoline and Oil, Average, 40 cents per gal.		..	290,000
Hydrogen ($1 50 per M, materials only)		..	25,000
Total per year			$1,400,000

$$\frac{1{,}400{,}000 \times 1000 \times 1000}{4380\ (70 - 10) \times 0.336 \times 150{,}000}$$

$=$$106 per 1000 lb. per 1000 miles

[6]For a 2,000,000-cu. ft., 2480-hp. airship, on a steady route of 1000 miles daily, except when laid up for repairs. The ship is assumed as being laid up one-half the total time and to be running the other half of the time at an average of two-thirds the maximum horsepower, giving an air-speed of 70 m.p.h.

ing capacity increases very markedly with increase of distance. One would expect this, but I think no one expected such huge sizes. For instance, a route of 4000 miles, which corresponds to many feasible distances across the Atlantic, requires a ship of 3,000,000 cu. ft. of gas capacity to negotiate it at all at a speed of 70 m.p.h. The dirigible R-34 had a speed of slightly over 50 m.p.h. To obtain reasonable economy, judging from the cost curve, we must go up to at least 10,000,000 cu. ft., and for maximum economy to about 50,000,000 cu. ft., which is far larger than anything we have at present. I have not assumed any radically new discoveries in the way of design or other improvements of that kind, other than mere size alone. I have worked out the steamship, the railroad and the motor truck on rather a similar basis, using the best authorities obtainable for the effect of length of haul and the mileage cost.

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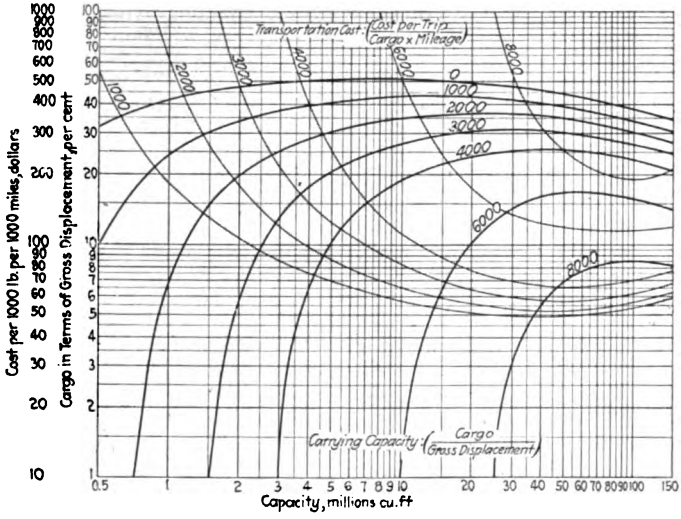

FIG. 1—CAPACITY AND COST CURVES OF COMMERCIAL AIRSHIPS BASED ON AN AVERAGE AIR SPEED OF 70 M. P. H.

INHERENT VALUE OF SPEED

We come next to the factor of time-value, or the inherent value of speed. That is already a well recognized factor in American transportation, but it is especially important in aircraft, which claims speed for its great prerogative. In fact, it would not be very far outside the limits of what is justifiable to agree to forget about everything else and to say that if the airship and the airplane cannot succeed on a basis of speed, they cannot succeed at all. The method of measuring the time or speed-value is of course an important matter. I have taken that in the very simplest terms, as represented by the value of any given goods per hour per 1000 lb.; that is, if we have 1000 lb. of material of some kind on which it will pay us to save 1 hr. of time, we figure what the saving is and that is the gage of how much we are able to pay for increased speed. So, we will take the time-value of the cargo in terms of dollars per 1000 lb. per hr. For example, suppose some fruit is ordered from California for delivery in New York. If it came by the ordinary slow freight, a large amount would spoil. It costs more by fast freight but the net economy is greater if we save enough of the consignment to make up for it. This is the big factor that must be taken into account in all analyses of air-transportation proposals.

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Fig. 2 shows the development of the principle for one particular type of carrier, the airship. This is prepared from about 1000 calculations, covering different conditions of use. The same method can be applied in principle to any form of transportation. The vertical divisions with figures at the bottom represent the length of route between stops. The horizontal divisions with figures at the left represent the time-value of the cargo per 1000 lb. per hr. Taking a route 3000 miles long and a cargo with a time-value of $1.70 per 1000 lb.; starting with a value of $1.70 at the left, we run horizontally over until we strike the 3000-mile mark, and spot the intersection; the curved lines running through the same point give the other data that are sought. First of all, take the line which is marked "transportation cost." This shows an actual cost of transportation of $53 per 1000 lb. per 1000 miles. The size of ship for the maximum ultimate economy in this case is 41,000,000 cu. ft. and the speed at which it is most economical to travel is 65 m.p.h. It will, of course, be said that these sizes are out of reach of present construction. They are, to the extent that we have not produced them yet but, as mentioned before, this requires only engineering work and involves no new discoveries.

Fig. 3 is a general combination in a rough way of different transportation systems that will be available after proper organization of the aircraft systems. This

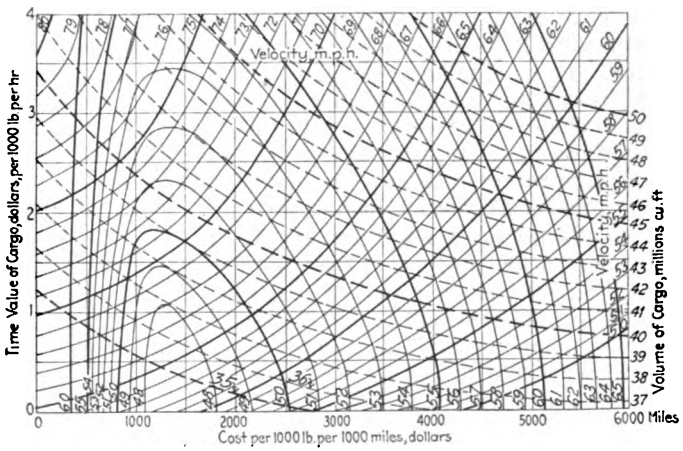

FIG. 2—CURVES SHOWING THE ECONOMIC VALUE, SPEED AND COST FOR CARGO OF VARYING TIME VALUE CARRIED OVER VARYING DISTANCES

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is worked out on a somewhat different basis, to simplify it. On such a broad scale we cannot include all the different routes that we did with the airship alone; hence we take for each of the primary systems, the railroad, the steamship and the airship, an assumed route of 1000 miles. For the secondary systems of motor truck and airplane, we take a route of 200 miles each. Along the bottom we have the net effective speed in miles per hour. In Fig. 2 it was in terms of the air speed of the airship but, in a combination chart of this kind, that does not mean anything. A fast freight-train on a railroad may go 17 m.p.h. while it is running but it may spend as long a time waiting for other trains to get by. So it has been necessary to work out all the different factors involved and arrive at some kind of estimate of net speed, including the time required to get in and out of terminals, and to load and unload. In explanation of the motor-truck curve I would say that I have not assumed in this case any time or cost charge for loading or unloading. The vertical divisions in Fig. 3 are on a logarithmical scale. This scale runs from a transportation cost of 10 cents to $10 per 1000 lb. per 1000 miles.

The steamship is the only carrier that gets below $1 per 1000 lb. per 1000 miles even under the most favorable conditions possible. Actually, it will cost more than that for usual conditions, including partly filled boats. As I said, Fig. 3 is for ideal conditions all the way through. The railroad comes next in cost and the airship next to it. The airship curve is very nearly horizontal until it finally shoots up when it gets to about 100 m.p.h. It is usually assumed that the airplane exceeds the airship in speed; but it must be noted again that Fig. 3 shows effective speeds and not the actual speeds; we are basing our figures on what we have in actual operation at present. It is a perfectly logical development from present knowledge and material.

The distinctive fields for these different transportation systems are shown in Fig. 3 in the form of shaded areas. The line of figures below the speed figures gives the time-value of the cargo in dollars per 1000 lb. per hr. The economic range for steamships is from zero to 10 cents per 1000 lb. per hr., which is represented by the shaded area running from 4 to 7 m.p.h. The railroad starts where the steamship leaves off, which makes it appear paradoxical to have a gap in the speed-range. However, reflection will show why it occurs. The

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economic railroad-range starts at 10 cents and runs up to $1 per 1000 lb. per 1000 miles. I am assuming that one might ship by either water or rail. Again, beyond the railroad speeds we get a big gap up to where the airship begins to be effective. It is not a gap in an economic sense but from the practical standpoint of speed. The airship does not begin to be able to compete with the railroad, with an effective speed of 19 m.p.h., until it reaches about 52 m.p.h., which includes landing and all else; economically it starts where the railroad leaves off, at $1 per 1000 lb. per hr. The motor truck and the airplane cannot be worked into this particular scheme because the latter's chief value depends upon the special uses to which it can be put. This is inclusive of non-schedule work, for instance, and all work of limited

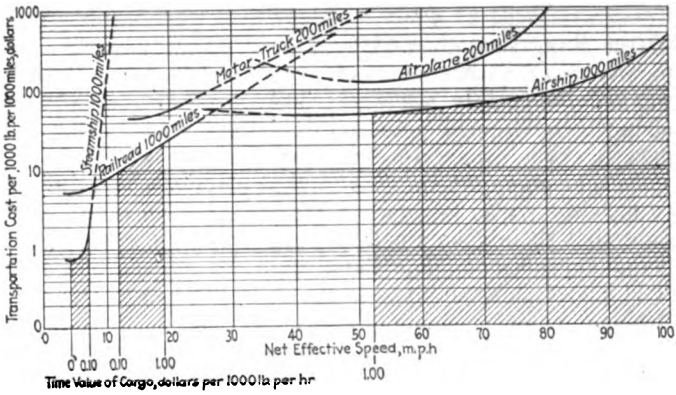

FIG. 3—COMPARATIVE COST OF FREIGHT TRANSPORTATION BY STEAMSHIP, RAILROAD, MOTOR TRUCK, AIRPLANE AND AIRSHIP

capacity, where the carrying of limited loads is required and it is necessary to make exceptional speed over short distances with small loads; finally, in the case of the motor truck it includes the supreme advantage of being able to deliver to destination.

TIME-VALUE CARGO CLASSIFICATION

I will outline briefly in practical terms what it means to classify cargoes according to time-value. For the steamship, which worked out from zero to 10 cents per 1000 lb. per hr., this includes all bulk cargo up to a capital value of $10 per lb., which comprises everything

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in the nature of coal, ore, stone, wood, castings or anything of similar nature that is not affected by time, other than a moderate interest charge on the investment. For railroads the economic range is up to $1 per 1000 lb. per hr. This includes all non-perishable bulk cargo up to $100 per lb. capital value; the airship starts from there and goes on up. So, it is evident that until we reach such things as jewelry, gold and silver, the capital value does not have much influence; but items that have perishability, such as news value, or human value, including passengers, mail and anything of that type in which time itself is of importance, do make a huge difference. I cannot enumerate all of the different articles which belong in this classification. Among other things the aircraft class includes all mail and practically all passengers, for long routes. The passenger problem is a study in itself.

One thing that must be kept in mind in all these comparisons is the difference between day and night. I have worked the points out on a uniform basis to be consistent, but most commodities and practically all passengers will pay more for the saving of time in daytime than at night, so that any carrier which is limited to daytime travel is under a very great disadvantage. I hope that the airplane will be worked up to overcome that disadvantage soon. For the airship, we can say now that it is easier and safer to handle at night than in the daytime.

We are on the threshold of aerial navigation. We have airships in sizes up to 2,000,000 cu. ft. that could be run at a very fair profit with goods of a time-value of $4 per 1000 lb. per hr., or with passengers whose time is worth $8,000 per year or more. This is for airships which are in operation at present. The transportation cost can be cut down more than 75 per cent merely by standardization of methods, organization for the purpose, designs which are suitable and, particularly, enlargements in the size of airship units. In this respect I believe that construction and operation must go together at the start. The more closely we can put them together, the better it will be. Furthermore, airships and airplanes should be operated simultaneously and in close cooperation, because they reinforce and supplement each other in almost every possible way. The general tendency at present is to get away from thinking in terms of any

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particular types. We are coming to the time when, with the growing recognition of the importance of air-travel development, we will not talk so much about designing the Zeppelin type of airship, the all-metal airplane or any other particular type. Instead, we shall go after the suitable type as an engineering problem and work it out to suit the conditions best. When we shall have done that, we will find that nothing we have done in the way of calculating the amount of available business will approach the actual possibilities. When telegraph lines were first being put in 100 years ago and even more recently than that, particularly when the cable was laid under the Atlantic, the question of what business the lines would attract might have been asked. Then we were in the position of having to charge rates for the transmission of messages over 100 times as much as those for transporting letters over corresponding distances. It might have been argued that no message could be so important as to justify such a large increase in cost. It is impossible to analyze a new business completely. The interesting fact is that the establishment of the telegraph lines and cables created their own business in large measure. In the case of the airship, when we are so organized that we have a network of airship transportation all over this country, it will be feasible to segregate and specialize our different manufacturing industries much more closely than we do at present. We could produce all our milk on one central farm and ship it to every point in the United States for a few cents per quart. I do not say that this will be done but such a thing is possible.

APPENDIX

The assumptions used as a basis for the calculations are as follows:

(1) All carriers are considered as being fully loaded

(2) The most economic size and number of units are considered, according to Tables 1 to 5

(3) The present methods of design, construction and operation are considered, with an allowance made only for change in size and standardization

(4) Invested capital is charged at 8 per cent per year

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Fuel cost is taken as follows:

(1) For the steamship, fuel oil at $18 or coal at $7.70 per ton of 2240 lb.

(2) For the railroad, coal at $6 per ton of 2000 lb.

(3) For the motor car, gasoline at 30 cents per United States gal.

(4) For the airplane and the airship, gasoline at 35 cents per United States gal.

Inclusive of construction cost, materials are assumed to cost as follows:

(1) For the steamship, 23 cents per lb. for the powerplant and 12½ cents per lb. for the remainder, which is mainly of steel

(2) For the railroad, locomotives at 18 cents per lb. and 8 cents per lb. for the remainder, which is mainly of steel

(3) For the motor car including the powerplant, 80 cents per lb., mainly of steel

(4) For the airplane including the powerplant, $4 per lb., utilizing steel and duralumin

(5) For the airship, $5 per lb. for the powerplant, mainly of steel; and $8 per lb. for the remainder, utilizing duralumin and fabric

The cost per mile is estimated on a basis of great-circle distance. For the steamship, railroad and motor car the average actual routes assumed are 33 per cent greater than the great-circle route; for the airplane and airship, the route is the same as the great circle.

An allowance of 6 per cent is made for heavy seas in the case of the steamship; about 40 per cent for switching and the like, slightly varying with speed, for the railroad; and about 10 per cent for bad roads, towns and the like for the motor car, varying slightly with the speed. For the airplane, the average cruising speed is taken at three-quarters of full power, further reduced by 11½ m.p.h. to allow for average winds. The average cruising speed of the airship is taken at two-thirds of full power, further reduced by 10 m.p.h. to allow for average winds.

The terminal time in and out, including the handling of the cargo, is from 4 to 8 days for the steamship, depending upon its size; 1 to 2 days for the railroad, de-

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pending upon the speed; none for the motor car; 1 hr. for the airplane; and 2 hr. for the airship. No allowance is made for delivery, which is too variable to consider.

The proportion of running time per year is about 55 per cent for the steamship, varying slightly with speed and size; 12 per cent for the railroad and 50 per cent for the motor car, varying slightly with the speed; 33 per cent for the airplane; and 50 per cent for the airship.

THE DISCUSSION

C. D. HANSCOM:—As I understand it, Mr. Upson has compared the future airship with the present-day steamship, railroad and airplane. Would it not be better to compare the airship with the same period of development of the other means of transportation?

R. H. UPSON:—I have been very liberal, particularly with the airplane. The cost which I have worked out for airplane transportation is less than one-tenth of what is being paid by the United States Aerial Mail. The airship costs are based on airships of present size, with a variation only in respect to the possibilities of size. It is wholly a matter of engineering that I am bringing up, not one of invention or of new discoveries.

MR. HANSCOM:—It seemed to me there was the possibility of cutting the cost to one-quarter.

MR. UPSON:—I have assumed an airplane with a gross limit of 15,000 lb., which is rather big for present-day service, and I have taken the most favorable estimates of efficiency for that purpose.

MR. HANSCOM:—That would approximate the conditions they have with the aerial mail.

MR. UPSON:—No; the aerial mail is costing over 10 times as much.

PROF. E. P. WARNER:—It is very desirable and necessary that night services be put into effect. I would like to know how Mr. Upson reconciles his advocacy of the single-engine plane with the desire for night flying.

MR. UPSON:—I was merely citing some interesting personal observations of particular planes that have come within my field of experience. I hold no brief, necessarily, for the single-engine machine; it is all a matter of suitability and design. If we are going over a country where it is of the utmost importance to have reliability and it cannot be had in any other way, we can multiply the number of power units.

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MAJOR L. B. LENT:—The Aerial Mail Service has been running between New York City and San Francisco since September, 1920, with several stations in between, and other branch lines, between Chicago and St. Louis and between Chicago and Minneapolis, have been running. We have been keeping accurate account of the cost of this service. While the Army and the Navy have been very good to us in supplying needed equipment, the cost of all the equipment is charged against the Aerial Mail Service and the Post Office Department figures, which are available to everyone, are accurate and can be relied upon. The cost, as we figure it because of our variable loads, runs about 70 cents per mile the year around. With proper equipment and an organization which might be developed that would be unhampered by law and regulations, I think that cost could be cut in half.

Our experience has taught us that the only excuse at present for a multi-engine plane is to get that plane from one major stop to another without a forced landing. We have forced landings from two causes, the weather and engine trouble. I think we should change from one engine to three. If one engine of a two-engine plane quits, we have lost 50 per cent of the power. If the plane is fully loaded, we have not enough power to drive the machine on to a major station where it can be landed properly and taken care of. Right there is an item of the cost of our Aerial Mail Service that is enormous, in comparison with actual operating cost. This maintenance and repair cost is much higher, including bringing in the machines from forced landings, when it is impossible for them to get out or they are damaged in getting them back to a repair station, replacing parts and putting them in flying condition. The other large maintenance cost has already been brought out. The planes we are using today are revised war-planes. The trouble we have in keeping these planes in flying condition is unbelievable, unless one encounters it from day to day. We have to deal with it because we are flying in all kinds of weather. Our performance is from coast to coast; it has not been as high as it might have been.

In speaking of the types of carrying plane, I think it is better, from the commercial standpoint, to divide the load between a number of single-engine planes. If the total load is carried in one plane and it has a forced landing, the whole service is delayed; while, if the load is distributed among four planes and two get through, at

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least one-half of the service has been performed. Where aerial trade is predicated on delivery of goods within a specified time, the customer demands that those goods be delivered.

Returning to the question of maintenance, the Society of Automotive Engineers has a work to do which I think is most important and that is practically to clean up the present type of plane so that it will be reliable. In a small way the Post Office Department is trying to do this. Usually engine failure is not due to faulty design but to the auxiliaries of the plant such as shaky radiator fastenings, small gas leaks and ignition apparatus out of commission. When coming in out of the snow, a rudder might be ripped off and so on. There is no more excuse for an unreliable gas system in an airplane than in an automobile. That part of the airplane must be made reliable. When those little things that are sources of constant annoyance shall have been cleaned up, we will have an airplane that has a fair amount of reliability.

The Aerial Mail Service has been running about 2½ years. If we could proceed as we would like to proceed, we could accomplish many things that we cannot accomplish now. But the record of the Aerial Mail Service will show that commercial aviation is a real, practical problem. The cost is not excessive and it can be reduced readily. I am informed that there is a large volume of business which can be had and would pay rather good dividends on the cost of operation. It may not come in the very near future, principally because the landing-fields and routes have not been laid out. Places to land, places to take care of the machines and a complete organization equipped with repair shops and all paraphernalia on the ground are necessary to keep a line in constant operation. There is a vast difference between fair-weather flying when it appears desirable and running a commercial aerial line on a schedule. Ability to fly in any weather will come, I think, very shortly. The one thing that hampers us now in flying is having to wait for good weather. The pilots will not go above the clouds and fly because they do not have the necessary navigating instruments to find their way. Wireless apparatus is available which will enable a pilot to fly above the clouds and come down and find his field. He actually can talk to the stations and find out where the landing-field is. We have done that. In landing at night, the incoming pilot can notify the landing-field and flyers can be sent out to meet

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him, even long after dark. Until we can fly above the clouds and disregard landmarks we will be handicapped in commercial work. The pilot flying over the Allegheny Mountains flies under the clouds, practically brushing the treetops all the way from New York City to Cleveland. That may be all right for carrying mail, but passengers cannot be carried in that way. The next step in real development is to secure more reliable airplanes by paying attention to the auxiliaries. I think we are not very far from such accomplishment.

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ECONOMY AND PERFORMANCE DEMANDS

By J G Vincent[1]

Stating that economy and performance are diametrically opposed in that the greater the performance demanded the less the economy is likely to be, the author mentions that the gasoline bill of the average user is not the major portion of his expense and asserts that economy is determined very largely by the engine design, the chassis design and the tires. The subject of engine design is outlined and consideration is given to acceleration during periods of coasting.

Discussing briefly the chassis and the tires, attention is given to oil and tire economy, followed by statements regarding design from the viewpoint of service and performance as influenced by gear-ratios and gear-shifting.

Economy and performance are diametrically opposed to each other. In other words, the greater the performance demanded, the less the economy is likely to be. Peculiarly enough, when economy is mentioned, the average user thinks only about gasoline economy. On account of the fuel situation, it is very important that we work for greater gasoline economy; but if it were not for that, I think it would not be so important. As a matter of fact, the gasoline bill of the average user having an average car is not the major portion of his expense by any manner of means.

Regarding gasoline economy and supposing that we are considering gasoline economy on a type of car that has what is considered good performance, a car that will go nearly everywhere on high gear, such a car must have an acceleration from 5 to 30 m.p.h. in from 12 to 14 sec. The economy of that car is very largely determined by the engine design, the chassis design and the tires. I will point out the problems as I see them, because I do not know their solution. I wish I did.

Engine Design

The engine design is greatly limited in a certain way; that is, the economy is limited by the demand for performance. We can design an engine in any one of three

[1]M.S.A.E.—Vice-president in charge of engineering, Packard Motor Car Co., Detroit.

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ways. We can take a small engine, run it at high speed and use a big gear-reduction. We can go to the other extreme and design a large engine, run it at slow speed and use a small gear-reduction. We can design an average-sized engine, with an average gearing. The high-speed engine would probably be geared somewhat above 5 to 1, the average being about 5.25 to 1; the slow-speed engine might be geared about 2.50 to 1 or 3 to 1; and the medium-speed engine about 4 to 1 or somewhat lower. Granting that the engine is of good modern design and well built throughout, I believe there will not be much difference in economy between those three types of engine, provided the design is equally well carried out. I base that statement on the fact that the larger engine is likely to have to have slightly lower compression and to be somewhat less efficient; probably it will have less friction at the speed at which it normally runs.

I think we do not all realize that, whereas with a moderately light car having everything tuned-up right we can drive say at 25 m.p.h. and get 20 miles per gal., if we could eliminate all the friction in the chassis and all the power that is required to turn the engine over, we could get 56 miles per gal. I am not in a position to prove this statement, but we have made some very exhaustive tests. I believe we have been attributing too much of the lack of economy in engines to throttle conditions, and that we have not been paying enough attention to the friction, particularly the friction of the engine which requires horsepower to turn it over. In other words, we are burning much more gasoline to turn the engine over than is required to drive an average car 25 m.p.h. This will bear investigation.

As to the chassis, there are many good types of design. It is not my task to discuss design, except to say that the chassis should be of well-balanced design in which friction is cut down to the lowest possible minimum, and that the adjustments should be so easy to make that the driver will not be compelled to drive the car with dragging brakes, or anything of that kind.

Tires

Considerable progress has been made in the quality of tires. I believe most of the best-known tires today, especially those of the cord type, give about uniformly good results. There is such a thing as over-tiring as well as under-tiring a car. Tires of adequate size only should be

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installed; I do not believe in what might be called the over-sizing of tires. I am assuming, of course, that the tire is properly selected in the first instance.

In the matter of oil economy, I think it is possible to obtain too much oil economy at the expense of something else. When we did not have the oil under control, we were constantly trying to reduce the oil consumption. I have been astonished to find out how little oil I could use but, after more experience, I learned that this reduced oil consumption was not all that I had thought it would be. With less lubrication, particularly with decreased cylinder lubrication, I found that I got into many other difficulties such as increased condensation in the crankcase, general wearing-out of piston-rings and the like. So long as we use the present fuel we will have trouble with condensation in the crankcase and with the oil. Therefore, the oil should be changed occasionally. The best way to insure that the oil will be changed is to use a reasonable amount of it, although not enough to cause trouble.

Tire economy is an important item of saving. We will get the best tire economy if we build chassis with good brakes, smooth engines and gearboxes, so that we will get a smooth pick-up. An all-around smoothly operating car will give the best car economy per ton-mile. We cannot lay down rules as to how large or how small we will build cars, because different kinds of people demand different kinds of service.

Service Requirements

Another item that is apt to be overlooked in some cases is the matter of design from the viewpoint of service. The principal items, aside from the first cost of the car, are probably tire repair and depreciation. Tires, next gasoline and lastly oil are the main supply items. Service will cost in proportion to how simple, sensible and reliable the design is. We should pay more attention to simplicity. We think we have been paying attention to reliability and, after that, simplicity and accessibility. All cars have been offenders to some extent in lack of accessibility. It is good experience to operate some of the newly designed cars and to maintain them oneself for a few months before talking about turning them over to the factory; in that way one finds out what parts must be taken off to gain access to some other part that requires attention.

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As to the matter of performance, I am inclined to agree that people do not like to shift gears, because they are hard to shift. We must recognize the fact that greater gasoline economy requires more gearshifting. We have been making the gearshift harder because, as the parts speed-up per mile traveled, the parts that must be handled in shifting gears increase in effective weight rapidly. Still, there has been much improvement along the line of gearshifting. Whether the gearbox should have consideration I am not prepared to say. Certainly it should if we make any great changes in the matter of performance. In other words, in the interest of economy we may approach nearer to the European type of car and if so we must improve the gearshift. [The discussion of this paper is printed on page 90.]

COMMERCIAL AVIATION IN THE EASTERN HEMISPHERE

By Edward P Warner[1]

This paper is illuminative and affords an opportunity for better comprehension of the remarkable progress and accomplishment made in Europe along the lines of commercial aviation. Reviewing the present European routes now in regular or partial operation, the author stresses the essentialness of the attitude of the press in general being favorable if commercial aviation is to become wholly successful.

The airship appears most practical for long-distance service, to the author, and he mentions the possibility of towns and cities growing up around "air ports." The cost of airship travel is specified, although it is difficult to figure costs and necessary charges because so few data on the depreciation of equipment are available.

Regarding successful operation, much depends upon the efficiency of the ground personnel and organization. It is present practice to send out to aviation pilots by radio telegraph hourly weather warnings which give the height of the clouds, the degree of fog at ground level and details of visibility.

Following a discussion of the matter of Governmental subsidies, the author describes the different kinds of machines and states many of the advantages and disadvantages of single and multi-engine aircraft, his

[1] Jun. M.S.A.E.—Secretary, sub-committee on aerodynamics, National Advisory Committee for Aeronautics, Langley Field, Va.

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opinion being that multi-engine machines are necessary, especially for extremely large units.

The main subjects considered thus far include the necessity of securing public confidence in the safety and reliability of the service, insurance, governmental assistance, the Air Convention, the matter of passports and visés, customs airdromes, the status of manufacturers, enclosed cabins, the materials of construction, the desirable number of engines, marine aircraft and the possibility of using transferable packing-cases. The illustrations show a few of the types of airplane most commonly used in transport and "taxi" service.

Commercial aviation in Europe as in America may be said to have sprung full-fledged into being shortly after the signing of the Armistice. Although attempts had been made at commercial flying before 1914, a few wealthy men having used airplanes for hasty trips from one city to another and some abortive attempts having been made at mail carrying as a "stunt," the flying done had no real significance except as propaganda for the airplane in general and had little more significance in that respect than had the exhibitions which were a common feature of State and county fairs and other fêtes in this Country. One exception must be made to this statement. The Hamburg-American line had been running, with the Schwaben and other Zeppelin airships, lines between some of the large cities in Germany, as well as making excursion tours over Berlin, and had been meeting with some success, although the public support probably was not large enough to make the operation of this line a paying venture aside from its value in developing the airships and in giving data on their operation which were subsequently put to military use.

The enormous development of aircraft under the stress of war not only increased the reliability of airplanes and airships and made it more practicable and safer to employ them in commercial flying, but it also awakened the public to the fact that flying is a reality, that it is a mode of locomotion possible for everyone and not merely for a few supermen, trick bicycle riders and acrobats; and it furthermore involved the creation of a large supply of aircraft which inevitably stood idle after the signing of the Armistice and invited every effort to find for them some new non-military use. Commercial flying, despite these incentives for its commencement, was a little slow in starting after the coming of peace, as all European governments hesitated to throw open the air

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in their territory to indiscriminate navigation before they had had a chance to make a thorough study of the conditions to be imposed on such navigation and of the control which would have to be exercised in the interests of the safety of the State and the safety of its nationals.

Civil flying in England was officially opened under authorization of the Air Ministry, May 1, 1919. Although a little passenger-carrying had been done over the Easter week-end, 10 days before that date, it had been strictly limited to service types of machine and to ex-service pilots and to flights extending not more than three miles from the home field. On May 1, however, the Air Ministry issued its regulations for the operation of civil aircraft, and those regulations are substantially the ones under which flying is carried on today, as they were nearly identical in most respects with the terms of the International Air Convention adopted by the Peace Conference of Versailles.

For the first few months after the official opening of civil flying in the British Isles, the work was confined to passenger-carrying by special request and to attempts on a small scale at the carrying of mails within the British Isles. This mail carrying, like all that which has since been done in the major European countries, was done by operating companies receiving a fixed fee from the Government. No European power operates its own mail planes, as has been the practice here.

International flying between England and the Continent began Aug. 26, 1919, the International Air Convention having then been drawn up and ratified by the principal states. A line between London and Paris was started at once to carry passengers, express and mail, but the mail carrying was of negligible importance for a considerable time, as the rates charged for postage were almost absurdly high; the letter postage being 2 shillings at first. The postage and the express services were well patronized from the beginning and the first line was soon joined by several others, so that there are now five distinct services in operation between the London and Paris terminal airdromes. In addition to these services there are now functioning regular lines between London and Brussels, London and Amsterdam, Paris and Brussels, Bordeaux and Nice, Amsterdam, Hamburg, Copenhagen, and Berlin, Toulouse and Casablanca via Tangier, and on a few other less important routes. This does not include a number of services which are adver-

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tised as regular but do not, as a matter of fact, run except on particular occasions when passengers offer themselves. In Germany, for example, there are fixed fares over about 100 routes within the German Republic, but no regular journeys on fixed schedules except in one or

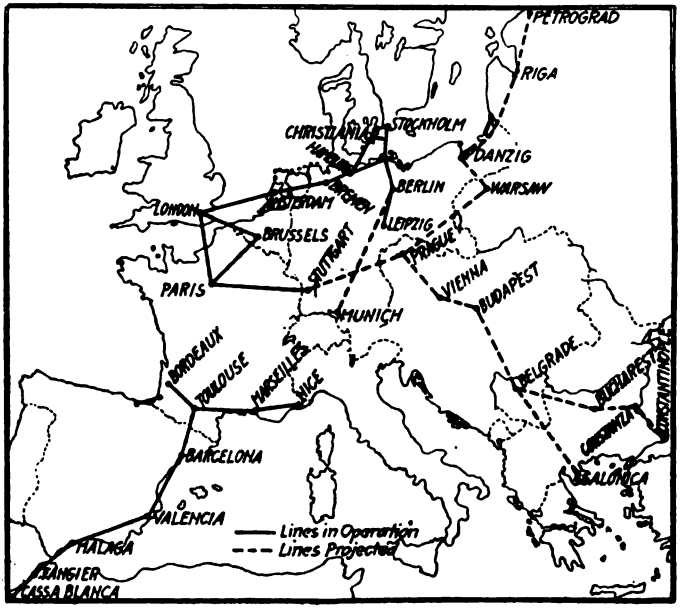

FIG. 1—PROJECTED AND REGULARLY OPERATING AIR ROUTES IN EUROPE AT THE BEGINNING OF 1921

two instances or except on such special occasions as the Leipzig Commercial Fair when numbers of passengers were carried from Berlin by airplane. Much more ambitious projects also are under consideration, one in particular being planned to connect Paris with Central and Eastern Europe, the fundamental line being from Paris to Prague with extensions leading to Warsaw, Nish, Salonica, Budapest, Constantinople, Bucharest and Constanza. The lines in operation and projected are shown in Fig. 1. Some routes of course offer much more favorable opportunities than others for aerial transport. The chief requirements for a good airplane route are that the traffic shall be large and wealthy, that the terrain shall not be excessively wild or mountainous, and that surface travel shall be slow and uncomfortable. All

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of these requirements are satisfied in the highest degree by the London-Paris and London-Brussels routes, the Channel crossing in a small steamer in bad weather, with two trans-shipments of hand baggage, being an atrocity of the first order. Again Great Britain finds the Channel of assistance in building up the potential means of national defense, this time in a most unexpected and indirect way.

The international services were not well patronized during the winter, but the traffic increased steadily during the past summer. During the month of July, 933 passengers traveled from London to Paris by air and 10,554 letters were carried between England and the Continent and goods to the value of £100,750 were imported into and exported from Great Britain by air in August. The number of commercial aircraft crossing the Channel increased from 140 in September, 1919, to 486 in August, 1920, and the average size of the airplanes in use also increased constantly.

No airship services are running at present, but they are likely to be started soon both in England and in Germany. The Air Ministry has offered to furnish rigid airships to operating companies, and some long-distance service would probably have been started before now had it not been for the great economic tension throughout the world. In Germany, the Zeppelin company started immediately after the Armistice to operate a service between Berlin and Friedrichshafen with the Bodensee, a ship of only 700,000 cu. ft. but far more efficient than anything previously built. The Bodensee has since been enlarged, and the Zeppelin officials declare themselves anxious to re-start the service with the Bodensee and her sister ship, the Nordstern, as soon as they can secure guarantees from the Allies that these ships will not be confiscated under the terms of the Treaty of Versailles as soon as they are put in commission. The airship is the ideal vehicle for long routes with moderately heavy traffic, and there should be an excellent opening for trans-Atlantic lines and for lines from England to India and to South Africa. The civil service in India would be considerably more attractive if Calcutta were only three and one-half days from London and two weeks could be spent at home out of a three weeks' annual leave. The airship has little chance in commercial work, however, as long as the present difficulties with landing and housing persist, and it will be a success

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when, and only when, the mooring mast is perfected to a point where a large rigid airship can be moored out continuously and in all weathers.

The first necessity of passenger carrying by air is public confidence in the reliability and safety of the service. People are willing to send their letters where they will not trust themselves, and commercial passenger-carrying by air can never really succeed unless it has public opinion and a supporting press behind it. The British undertakings have been very fortunate in this respect from the first, and the commonplace manner in which travel by air is now accepted by the general public is amazing to a foreign visitor. On entering a tourist agency in London at the present time and asking for a ticket to Paris, one is regularly met by the matter-of-fact query, "rail or air?", and the same question is put when express packages are brought in for shipment to the Continent. There is one agency in London which handles air traffic almost exclusively, its other business being purely side-lines, the adjective "aerial" appearing in the very name of the corporation, and this agency has established itself on the ground floor on a corner in Piccadilly Circus, one of the busiest spots in London. The condition is somewhat comparable to that which would exist if an American airplane ticket-agency took space 30 x 45 ft. on the ground floor at the corner of Fifth Avenue and 42nd Street in New York City. In Germany the booking of air passages forms an important part of the business of the Hamburg-American agency in the Unter den Linden. That public confidence exists in so large a degree is largely due to the favorable attitude of the press which, instead of seizing every opportunity to present accounts of accidents under glaring headlines and to magnify their significance, has been uniformly friendly and has sought rather to emphasize the news favorable to aviation both in the news columns and editorially. The friendly attitude of what is probably the largest of all newspaper syndicates is traditional, Lord Northcliffe's personal interest in aviation having extended far back into the pioneer days and been expressed in concrete form by the offer of large prizes for the trans-Atlantic flight and other aerial feats.

No matter how friendly the newspapers may be, however, they can do no more in the long run than to make a fair presentation of the facts and it is impossible for commercial aviation to flourish unless the safety of flight

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is fairly comparable with that of other means of transport. In order that reliable data on this point may be at hand, the British Air Ministry has compiled statistics relating to accidents in commercial flying, both to furnish information on the causes of such accidents for designers and the best means of preventing their recurrence and to permit the public to judge fairly of the risk which they run in traveling by air. These statistics show that during the first eleven months of commercial flying in England and between England and the Continent there was a total of 24 accidents, four of which resulted in the death of one or more occupants of the airplane. The pilot was killed in all four cases, while in the whole 11 months one passenger was killed. The average death-rate among pilots was 0.415 per 1000 hr. or one death for every 2410 hr. of flying, while the average among passengers was 0.015 fatalities per 1000 passengers carried and 0.055 per 1000 passenger hr. This works out roughly at one death for every 67,000 passengers and every 18,200 passenger-hr. or, taking the average cruising speed of commercial aircraft as 90 m.p.h., as one fatality for 1,640,000 passenger-miles. During the year 1917 the passenger death-rate for railroad travel in the United States was one for every 3,220,000 passengers carried, a danger ratio of 48 to 1. In some years American railroads have shown themselves less than 20 times as safe as has the airplane in this, its first, year of commercial use. If the calculation includes all injuries as well as deaths, the relative showing of the airplane is considerably more favorable. The airplane death-rate is certainly very much less than the uninitiated would generally suspect, but it is still much too high and must and can be further reduced by research, by improvement in design, and by more complete and systematic ground organization, all of which call for Government aid.

Second only to safety in importance, and even ahead of it insofar as the carriage of mails and express is concerned, is economy. The cost of air service is still rather uncertain, as the lines have not been in operation long enough to give very many data on depreciation and running costs. The most exhaustive study to date is that made by H. White-Smith in a paper presented to the Air Conference held in London last September. Mr. White-Smith analyzed the costs of operating a service with several types of airplane and seaplane, including

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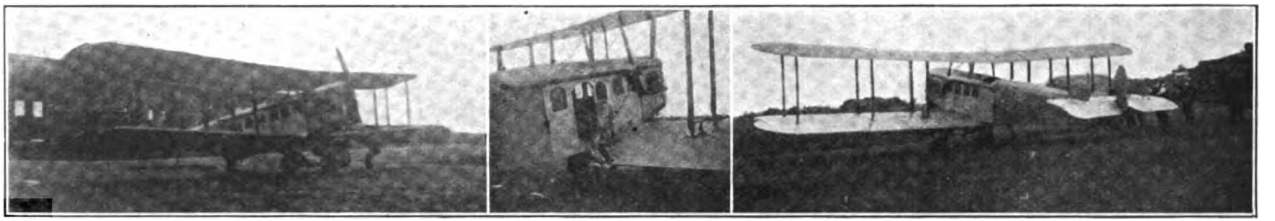

FIG. 2—FRONT AND REAR VIEWS OF THE WESTLAND LIMOUSINE AIRPLANE, WITH THE ENTRANCE TO THE CABIN IN THE SMALL CENTRAL ILLUSTRATION

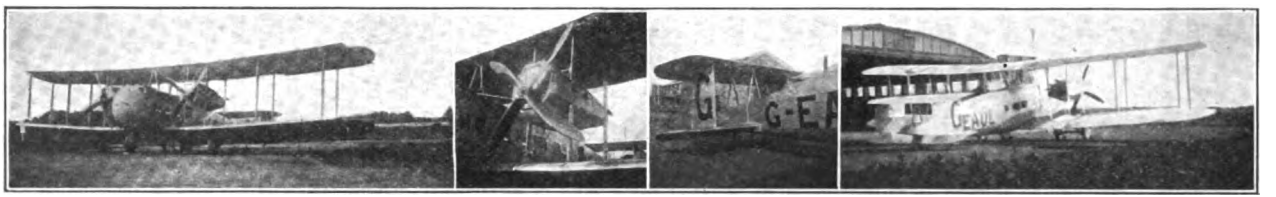

FIG. 3—FOUR VIEWS OF THE VICKERS VIMY COMMERCIAL AIRPLANE EQUIPPED WITH A ROLLS-ROYCE EAGLE ENGINE

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some new machines of commercial types and some converted service airplanes, and showed that the most economical machines, the largest ones in most cases, could operate profitably carrying passengers between Paris and London for £5, 10s. ($19.50 at the present exchange), if the machines could carry a full load on every trip. Mr. White-Smith's figures were based on a life of 3000 flying-hr. for the airplane and 2000 flying-hr. for an engine and included insurance against crashes at a rate of 15 per cent. The Canadian Air Board recently issued a memorandum on depreciation in which the conclusion was drawn that the life of an airplane under ordinary use is 700 flying-hr. and that the crash risk is 0.2 per cent every flying-hour, so, it is evident that there is still wide difference of opinion among the authorities on the basis to be adopted in calculating costs. In durability, as in safety, there is room for decided improvement, and there is no doubt that flying life will be much increased in the near future.

The actual costs have shown a tendency to steady reduction. The fare charge on the London-Paris route was originally 20 guineas but has since been decreased several times and now stands at 10 guineas ($37.00) for the one-way journey and 18 guineas for the round-trip. The fare to Brussels is the same, while that to Amsterdam is 15 guineas one way. The rate between London and Paris by boat and rail via Dover and Calais is £3, 15s., 8d., so that the excess of airplane fare over that for service transportation is 178 per cent. Frank Searle, manager of the Aircraft Transport & Travel Co., who was largely responsible for the reduction in rate, lays great emphasis on the necessity of reducing the fare still further to increase the use of aerial transport to a point where machines can be run in considerable numbers, thus decreasing the percentage of overhead to be charged to each trip and also in order that they can run regularly with a full load. Mr. Searle prophesied, in an interview in the London *Times*, the reduction of the London-Paris fare to £7 in the relatively near future. The fares on other services are of the same order except in Germany, where the extreme depreciation of the currency makes all costs ridiculously low when referred to American money. The fare between Berlin and Leipzig during the Leipzig fair, for example, was only 800 marks, the equivalent of about $15 as the exchange then stood.

The charge in England for an "aerial taxi" for two

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people is 2s. 6d. (44 cents) per mile, and an airplane can usually be had to start for anywhere on an hour's notice. This fare is only 2½ times as large as that for an earth-bound taxi in London, and it costs approximately the same amount to travel by airplane in England and by taxi in New York.

Insurance

An essential to any business is insurance, and that is now being handled by a number of firms. Particularly interesting is the invasion of the field by Lloyds' who have recently retained consulting aeronautical engineers with a view to registering aircraft and rating them as risks, just as they have done with ships for many years. It appears that the aerial, like the marine, underwriters will be far harder on the man responsible for an accident than will the State, and it has already been suggested that a crash in landing is absolutely inexcusable and that a pilot who once damages an airplane in landing on a good field should be made forever uninsurable.

Insurance rates at the present time are about 30 per cent per annum for passenger aircraft traveling over good country, with a reduction of 0.2 per cent on the face value of the policy for every hour of flying after the first 100 hr. Airplanes used for stunting cannot be insured ordinarily.

There are practically no data on which to base an estimate of the cost of an airship service, but Air Commodore E. M. Maitland has estimated that with ships similar to the R-34 a 15-per cent profit could be made carrying passengers from England to Egypt for £50, to India for £100, and to Australia for £190. These figures are from 10 to 70 per cent in excess of the first-class steamer fares, and the saving of time would be from 60 to 70 per cent.

Government Assistance

There is no European nation which has not clearly seen that the airplane can be kept in readiness for use in war only through the development of its use in commerce and that it is a clear function of Government to assist their use in commerce by every means in its power. The development of an air traffic under the control of its nationals is felt to be more important to many States than is the development of a similarly controlled merchant marine. In addition to the direct military usefulness of the airplanes developed for commercial

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work there is an additional motive in the value of air transport as a link between the home country or the dominions or colonies, and an analysis of the measures taken by the various Governments shows that this last incentive is always in mind and it has been the guiding star of such enterprise as the Government-encouraged, although not actually Government-assisted, flights from England to South Africa and from England to Australia in the development of the "Imperial Air Routes" of which more will be said later, and in the efforts of the French and Belgian Governments to steer air commerce in the direction of their respective colonies in West Africa. Every improvement makes it easier for the dominions and binds them more closely to the parent country.

If the necessity of Government assistance of some sort in giving commercial flying its start is conceded, there are four forms which it may take. It may be extended through direct purchases of airplanes for the military establishment or or other branches of Government, as is the case here. Secondly, it may take the form of a direct subsidy of the industry, of the payment of part of the costs of recognized airplane forms by the Government, thus making it possible to reduce the cost of operation of transport lines. A modification of this scheme, and one more commonly adopted, is the granting of monetary assistance by the Government to operating companies, instead of to manufacturers, on a basis of services actually operated and proportionate to the extent of the service. This is the system on which the French Government has chiefly proceeded and it is also to be adopted by the Polish Government to encourage the opening of the service between Prague and Warsaw. Finally, instead of granting any direct assistance to firms engaged in the manufacture or operation of aircraft, the Government may offer indirect assistance by furnishing the ground organization for the services and by encouraging research aiming to obtain fundamental data for the production of more useful and more economical aircraft. It is to this last method that the British Government has chiefly adhered up to the present time. At the time of the opening of commercial aviation, Winston Churchill, then Secretary of State for Air, voiced the opinion that commercial aviation must fly alone, and despite occasional protests and appeals for help the British Government has adhered throughout to

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that policy. The assistance granted in Great Britain has included the provision and upkeep of state airdromes open to both commercial aircraft and those owned by private individuals. Hangars can be rented at these fields and supplies and repairs of all sorts can be secured. At present, there have been listed over 300 fields in the British Isles which are available for use by civilian pilots; this does not include emergency landing places, but only regular elds kept in proper condition for the reception of aircraft. If flying fields were distributed with the same intensity over here there would be 130 in New York State alone. The number now available, however, is felt to be insufficient for convenience and safety, and it has been proposed recently that the major air

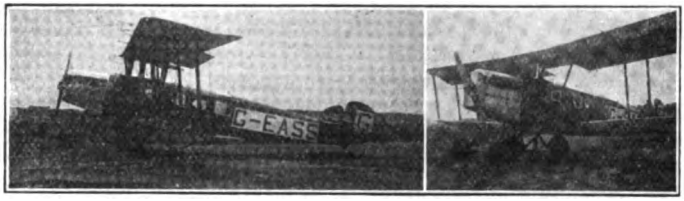

FIG. 4—A SIDE VIEW OF THE SOPWITH ANTELOPE AIRPLANE (AT THE LEFT) AND ONE OF THE NOSE OF THE MACHINE (AT THE RIGHT)

routes be marked by a continuous strip of cleared ground about 100 yd. wide, permitting of a forced landing at any point along the route. This strip would be lighted continuously for night flying and a charged cable would possibly be laid along the route to permit of electric direction-finding in a manner similar to that employed in recent experiments with shipping in New York harbor. No official steps looking toward such elaboration of the air routes have been taken as yet, however. The most notable achievement of the Air Ministry in long-distance route-marking was the laying out of a line of landing fields from Cairo to Cape Town, and another string partially covering the road to Australia. Great central airdromes for travel to the dominions have been established at Karachi and at Heliopolis, near Cairo. Furthermore, the State maintains an elaborate meteorological service preparing a special weather map for aviators daily and sending out weather bulletins by radio at frequent intervals throughout the day, and it has erected two aerial light-houses at Croydon and Lympne, the latter of which points lies virtually on the London-Paris

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route. Concerning the terminal customs airdrome at Croydon, I shall have something more to say later.

Night flying on regular services has not yet been undertaken because of the danger involved. If commercial flying is to exercise any large influence on travel except on a few selected routes of a very special character, it is absolutely essential that journeys be made at night, and this calls for decided modification in the types of aircraft employed. The London-Paris route, as already remarked, is a special case where night flying is not required, as the changes of vehicles required and the crossing of the international boundary make a night journey by the ordinary means of travel rather unpleasant, but that route has little bearing on our problems here, and a daytime airplane line between Boston and Washington, for example, could never hope for any very large patronage as long as the Federal Express makes it possible to make the journey without losing 1 min. of the business day. Night-flying airplanes must be multi-engined so as to be absolutely insured against sudden forced landings, they must be specially fitted for the convenience of the passengers, and they must have a reasonably low landing-speed. In general, the high speed need not exceed 90 m.p.h. Furthermore, night flying is absolutely dependent on the provision by either the Government or private enterprise of an elaborate ground organization, including numerous well lighted landing-fields and many aerial lighthouses or searchlight stations. In these respects the marine aircraft traveling between seaports and keeping over the water has a decided advantage over land types, as it can depend on marine lighthouses already established for finding the way and as it is nearly always possible to make a safe landing on the sea with the aid of a few parachute flares and lights on the seaplane, even on a moonless night.

The British Government, in addition to providing ground organization, has continued its research activities and distributed broadcast the results of the work done at the Royal Aircraft Establishment and at the National Physical Laboratory, much of which is now planned to have a special bearing on commercial aeronautics, and it has during the past summer held a very successful competition for commercial aircraft of three types, large land machines, small land machines and amphibians. British experience points a few lessons which may be of great value to us at present. In the first

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place, it has always been found that commercial and military aviation must be considered separately and that the necessary research work for the commercial side can best be carried out directly by a civilian body severed as far as possible from ordinary departmental administration. This place in Great Britain is filled by the Aeronautical Research Committee, formerly the Advisory Committee for Aeronautics, a body which is virtually duplicated in its organization and purpose and possibilities of usefulness in this country by the National Advisory Committee for Aeronautics. Secondly, foreign experience emphasizes the value of special competitions for commercial aircraft. There is no doubt that the British competitions aroused more interest among the manufacturers and did more to develop design for specifically commercial purposes than would an equal amount of money expended on purchases of designs already developed, and it is my opinion that we in America could do nothing more useful to encourage aeronautics than to plan to hold such a competition for purely commercial aircraft. The French also have had a competition, but theirs differed a little from the British one in that the French rules kept the possibility of military need always in mind and made it a condition of entry that the airplane must be of a type easily and rapidly convertible for use as a bomber.

The French Government has perhaps paid a little less attention to the establishment of ground services than has the British, but it adopted in September, 1919, an elaborate scheme of subsidization of operating companies. The subsidy is a maximum for services operating regularly between points at least 200 km. apart and is then equal to one-half of the depreciation based on an assumed life of 400 hr. for an airplane and 267 hr. for an engine. Under this system a service operating with a two-engine airplane carrying 12 passengers and costing $40,000 for the airplane without engine and $10,000 for the engines would receive an award of $75 per hr. of flight. Where the line is less than 200 km. in total length, the hourly award is halved. Additional bonuses are given for the length of voyage without stop, for the power of the engine, for the speed and for the useful load carried. Furthermore, the last two bonuses are proportionate to the nature and location of the service, being a maximum for services in the interior of Africa and a minimum for those in continental

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France. Here again will be noted the desire to use the airplane as a bond of empire. A still further premium is awarded for military value and for ease of conversion for bombing purposes, so that it would be easy for the airplane specified above to receive a total premium of $135 per hr. of flight or about 12 cents per passenger-mile. These premiums are available only for companies wholly French, using airplanes and equipment of French design and construction. To qualify for the premiums it is required that the total number of airplanes owned and kept ready for service as far as possible be at least three times the number actually in use at any given time and that the number of pilots be 50 per cent greater than the number flying on any particular day.

Other countries have done much less to encourage civil aviation. The German Government, owing to the restrictions of the treaty and its own impoverishment, has been unable to give any concrete assistance to German air-transport companies and little has been done by the Government in Italy or any of the smaller States. The Belgian Government is taking steps to give such support as is necessary to insure the establishment of service in the Belgian Congo and the Polish Government, as already noted, is offering a small subsidy to the company operating between Prague and Warsaw.

The Air Convention

The Governments come in contact with commercial aviation not only in extending that assistance which is necessary to keep it going, but also in exercising that measure of control which safety exacts. The control exercised is supposed to be practically uniform throughout the allied countries and those neutrals which have subscribed to the International Air Convention and the League of Nations, being regulated in detail by the terms of the Air Convention, which document provides for the licensing of aircraft and of pilot navigators and engineers, for the conditions to be observed in crossing International boundaries, and for rules of the road and lights and other signals. The Air Convention was originally intended to be a closed corporation, as it prescribed that every contracting State undertook to prevent the flight across its territory of any aircraft belonging to a non-contracting State, but a protocol was drawn up later permitting any State, which so wished, to nullify this particular clause, as the neutral States

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surrounding Germany had naturally protested against being required to bar out German aircraft until such time as Germany should be received in the League of Nations. The points of detail in the Air Convention which are of most interest to us are those dealing with international navigation. It is prescribed that any commercial aircraft of a contracting State shall have the right to cross the borders of any other contracting State without landing therein, subject to the following of such regulations as each State may lay down relative to the

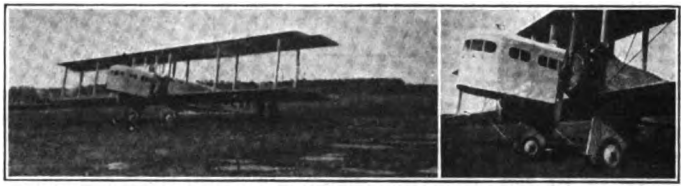

FIG. 5—SIDE VIEW (AT THE LEFT) AND VIEW OF THE NOSE (AT THE RIGHT) OF A FARMAN GOLIATH AIRPLANE DRIVEN BY TWO SALMSON ENGINES

prohibition of flying over military or other secret areas. It is further prescribed that an aircraft making a voyage from one State into another shall land at a prescribed customs airdrome and that any forced landing at the end of an international flight shall immediately be reported to the customs authorities. Each State is given the right to restrict traffic between two points within its own borders to aircraft owned by its own nationals and elaborate provisions are laid down against the camouflaging of alien nationality behind the names of native dummy directors. This is, of course, analogous to the provisions of the coastwise shipping acts in force in America and other countries. While the Air Convention should very much facilitate international travel by air, in practice some difficulties have arisen owing to the present unsettled state of Europe, and commercial aircraft have been forced frequently to land in a contracting State over whose territory the pilot had planned to pass without stop. The convention has, however, very much ameliorated conditions and international intercourse would be quite impossible without some such arrangement.

The Air Convention charges each contracting State with the duty of granting certificates of airworthiness and licenses to operating personnel. The conditions for

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the licensing of pilots are laid down in detail, the tests not being very difficult, but it is left to each country at least for the present to make its own regulations for the granting of the airworthiness certificate. In England a memorandum has been issued treating in detail of the load factors required in commercial aircraft and of the methods of calculation of stresses, and the design of every airplane flown for hire in the British Isles has to be examined, checked and approved by the Air Ministry. No European State has any intention of permitting, if they can be prevented, such catastrophies due to improper design as have occurred too frequently in the past. Every aircraft flying on Great Britain or any other contracting State is required to carry its official designation in the form of five letters painted on the side of the fuselage and also on the bottom of the lower wing. The first of these five letters designates the nationality of the aircraft, except that in the case of a number of smaller States having the same first letter the nationality is designated by the second letter. In accordance with the terms of the Air Convention, had the United States accepted them in full, every American aircraft would have been required to bear five letters registered at Geneva, the first letter being N. The total set of five letters forms the wireless call-signal of the aircraft.

Passports and Visés

The frequency of international boundary lines in Europe, particularly since the recent redrawing of the map of Central Europe, has both favorable and unfavorable effects on commercial flying. In a flight in which several States are crossed the traveler by air is saved much inconvenience, provided the intentions of the Air Convention are realized and the aircraft is not required to land as it crosses each boundary, as only one visé would be required, whereas one who journeys by rail must have his passport viséd for every country he is to penetrate; a rail journey from Paris to Constantinople, for example, entails weary days of waiting in the ante-rooms of the consulates of the various countries of Central Europe. On the other hand, the delay in waiting for a visé or to secure a passport is a much more important relative fraction of the time of an air than of a land or water journey. The value of being able to go from London to Paris in 2½ instead of 9 hr., for example, is much decreased if two days to secure

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passport have to be added to the time of both trips. The passport difficulty is fortunately being much ameliorated through the efforts of the League of Nations and other agencies, so that it is now possible for an Englishman having frequent business in Paris to secure a passport and a French visé both of which are good for one year.

Customs Airdromes

As already noted, all aircraft making international journeys must, barring emergencies, land at a customs airdrome. These airdromes are located at Croydon and at Cricklewood for London and at Le Bourget for Paris, and incoming aircraft are handled and their contents examined by the customs officials very much as are ships at a port. Incidentally, several attempts at smuggling by aircraft have already been detected. The Croydon airdrome is especially remarkable for a system of landing lights which indicates the place to land and the wind direction. Lights below glass plates sunk flush with the surface of the field are arranged to form four pairs of parallel lines, and a single switch controls each pair of lines. The pilot is supposed to land between and parallel to the two lines which are switched on. The direction in which the wind is blowing along the lane thus defined is shown by the arrangement of the lights at the ends.

Status of Manufacturers

No consideration of the status of commercial aviation would be complete without some discussion of the relations and the interactions between the operating companies and the industry. In most instances the companies operating in Europe have been distinct from those making the aircraft, although there are several exceptions, such as the Handley-Page, Airco, Zeppelin, Rumpler, and Sablatnig. This separation leaves the manufacturer dependent for support on the sale of airplanes in the open market, assuming that there are no direct Government purchases, and it forces him not only to produce a type which will attract the traveler by air, but also to attract the operating companies, his potential customers, by making aircraft that are durable and economical and easy to repair, and by furnishing prompt service when anything goes wrong; factors some of which have not entered very largely into the calculations of airplane builders up to the present time.

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The competition between manufacturers who must depend on a commercial market is certain to be bitter, for not even the greatest optimist can see any prospect of business that will support the number of producers now endeavoring to keep from the wall. The only hope for many of them, particularly those who have not the capital to stand a long siege and to carry on an expensive publicity campaign throughout the world, lies in the growth of a demand for small airplanes from private individuals, for the demand for new machines from the air-transport services, numerous though these services are, is still very small. In a week of good weather 120 airplanes, most of which are of British manufacture, make the trip between England and the Continent. Allowing three trips per week for each airplane in active service, it can be assumed that 40 airplanes are engaged in cross-Channel transport. If the life of a commercial airplane flying an average of 10 hr. per week is taken as 18 months, the maintenance of the Anglo-Continental air services at their present strength would require the provision of only about 30 new airplanes a year, a small demand on which to rest an industry of the scope of that which grew up during the war. Although there is no doubt of the absolute necessity of increased reliability and durability, any increase in life unaccompanied by at least a corresponding increase in the extent of the commercial use of aircraft, will serve merely to aggravate the difficult situation in which the manufacturers now find themselves. Their only hope lies in constantly continuing expansion of the use of aircraft. For commercial flying to rest on its oars, satisfied with its existing position either now or at any future time, would clearly mean the virtual extirpation of the aircraft industry and be a national danger in that it would put a stop to the manufacture of an article essential for national defense.

Enclosed Cabins

Granting that there is to be bitter competition for such commercial business as exists, it remains to be seen what policy the producer should adopt and what features he should incorporate in his design to appeal to the purchaser. First, as to general layout, an enclosed cabin will be required in all cases in order that flights can be made with comfort to the passengers in all sorts of weather. The cabin must not, however, be made so airtight in the effort to secure warmth that the air inside

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can become bad. Several enclosed-cabin designs have been notorious offenders in this respect, and I believe that a large majority of the cases of airsickness which occur in straight cross-country flying are at least as chargeable to bad ventilation as to bumps and unsteady motion. The enclosure of the pilot's seat has not found favor in post-war European designs, with one or two exceptions, but there seems to be no very good reason for this, and the pilots who have tried it have found no difficulty in controlling the aircraft from inside the cabin. Another element having an important bearing on the comfort and convenience is the ease of access to the

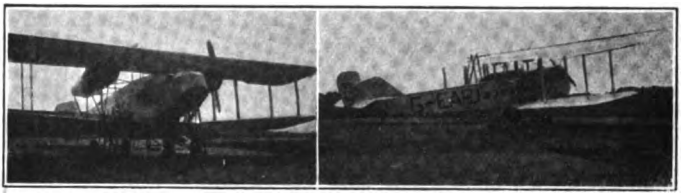

FIG. 6—NOSE AND SIDE VIEWS OF THE HANDLEY-PAGE COMMERCIAL AIRPLANE

cabin and the freedom of movement inside. No airplane in which the passengers must make their entry by arising through the floor or descending through the roof has any commercial future, nor has any machine in which the cabin is crossed and re-crossed by bracing wires through which the occupants must thread their way. These things are much more important than attractive upholstery, figured walls and window curtains which have attracted so much attention in some recent productions. Fortunately few European machines of the last year offend in respect of accessibility and comfort. The necessity of omitting bracing wires and of putting in the side of the fuselage a door at least 4½ ft. high and without any wires or other members across it, imposes a fuselage constructed of either metal or veneer upon the designer of this type of aircraft, with the preference lying with the latter of these two materials.

MATERIALS OF CONSTRUCTION

Reliability requires a decided change from the present type of construction. All-metal construction is still regarded with grave suspicion outside of Germany, and even by many Germans, but metal is certain to be used to a constantly increasing extent in struts, spars, con-

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trol surfaces and fuselages. In any case, fabric must go, in favor either of metal or of veneer. So long as the present rapid deterioration of the wing covering persists, the airplane cannot be regarded as a finished product for either commercial use or private ownership. It is my belief that the trend in non-military airplanes is toward veneer covering, such as is employed by Fokker on his latest products, rather than toward the metal covering made famous by Junkers and recently adopted in a different form by Short. Another material that has no proper place in large airplanes and has survived by reason of cheapness and simplicity of application, is the rubber in the shock-absorbers. Oleo and hydraulic gears in combination with relatively light steel springs have long been known and there is no reason why they should not have been used, especially on the largest commercial airplanes. Yet another point where change of material is necessary is in the propeller. The wooden propeller goes to pieces with amazing rapidity in rain or hail, and must be replaced by a screw of some more resistant material. Metal propellers are being experimented with extensively in Europe, and at least two, one of steel and one of aluminum, have reached the point of trial in flight. The bakelite propeller seems to fill the bill admirably, but it has not yet found its way across the Atlantic.

Number of Engines

The question of superiority between the single-engine and the multi-engine airplane has not yet been settled, and both types are in regular use. In order that a twin-engine airplane can maintain flight without losing altitude when one engine has been cut off, thus securing that added measure of safety against forced landings with which such craft are commonly credited, it must be very lightly loaded with full power and therefore be uneconomical as a vehicle for transporting useful load. When loaded for efficient commercial utilization it will certainly be impossible to stay in the air with the power reduced 50 per cent. A twin-engine machine which cannot hold the air with one engine cut off has obviously just twice as many chances of being forced to land by engine trouble as has the single-engine design, and a number of the operating companies are accordingly still clinging to the single unit. The easiest way around the twin-engine difficulty is to use light, high-efficiency engines of military type and not run them at

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full throttle under ordinary circumstances, thus prolonging their life and having a large potential power reserve in each engine to be called on in case of the failure of the other. This arrangement is preferable to the use of heavier and more reliable "commercial" engines run normally at full throttle only on twin-engine machines. The objection to the twin-engine airplane that has just been raised does not apply with nearly so much force when the number of engines is increased to three or four or more, and the commercial airplane of the future must be multi-engine unless it is to work over territory where a forced landing is possible at practically any point. Particularly if flights are to be made at night or over rough ground such as is found in the African colonies and on the road to the British dominions in the East, a multiplicity of engines will be essential. There is no tendency in any of the allied or neutral states to imitate the common German practice of keeping the powerplants central and gearing several engines together on a single large propeller, and this practice does not appear to offer any special advantages. The arrangement of engines in the Staaken giant is a much more promising development, as the distribution of weight along the span reduces enormously the stresses in the wing structure and makes lighter construction possible. This construction does, however, have the harmful effect of increasing the landing stresses, and such an airplane with cantilever wings, the Staaken is not a true cantilever job, could be landed only on a very smooth field where the several landing gears could be counted on to make contact simultaneously. The airplane with more than two groups of engines built into the wings must, therefore, to gain the full benefit of the distribution of weight, have enough powerplants and reliable enough ones that the possibility of a forced landing in a difficult field can simply be dismissed from the mind. Provision against forced landings in a large commercial aircraft should be so complete that provision for forced landings can be neglected. No naval architect attempts to design an ocean liner so that she can be run on the beach with impunity.

Marine Aircraft

With the total elimination of the forced landing as a factor, it will become safe to make overland journeys of reasonable length in flying-boats, and it seems to me inevitable that much of the air traffic of the future will

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be by marine or amphibious aircraft, because of the ease of finding landing fields near great cities. Nearly all of the world's great centers have their business districts immediately adjacent to a frontage on sea, lake, or river, and the ability to take-off from and land at any waterfront would usually shorten the total time of a journey by at least ½ hr. At the present time the trips from the center of London out to Croydon and from Le Bourget into Paris by automobile consume almost half as much time as the whole journey from Croydon to Le Bourget by air. Already there has been much serious discussion, although no official action has been taken, of setting aside a strip of the Thames as a landing-place for aircraft, and it was presumably with an eye to the saving of time at the termini of intercity journeys that the Air Ministry undertook to encourage the design of amphibious aircraft by providing a special class for them in the civil aircraft competitions of the past summer.

Transferable Packing Cases

The cargo of an airplane is small enough so that it can often be completed with a single consignment, or at least with a group of shipments for the same destination, and a company has recently been formed in London to carry express exclusively, especially over long distances, packing the consignment in a case designed simply to drop into the cargo space of the airplane used and transferring this case and its contents bodily from one machine to another of similar type at the end of each stage of the flight, thus saving the time required to re-fuel and inspect the machine just finishing its flight and starting the express on its way again with scarcely more delay than was involved in a change of mounts and a transfer of the mail pouch in the pony express of the old West. Although this scheme may work out satisfactorily, there are no two points in the Eastern hemisphere between which it could be used so profitably as between our own Eastern and Western coasts.

THE DISCUSSION

R. H. Upson:—In the matter of cooperation between manufacturers and operators, Professor Warner mentioned the fact that there seems to be a growing tendency in Europe to keep the operator distinct from the manufacturer. I do not contravert that statement of fact, but I do not object to the possible inference of its being a model to be followed, especially in starting out

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along new lines. It is of great importance to have just as close cooperation and connection between manufacturing and operating as is possible. I think it will be found that this has been the rule in Europe. Usually, the builders have supervised the operation very closely at the start, and only after it became standardized to the point where the separation mentioned could be effected has this been done. As an example, consider the German airship Bodensee. It was operated not only by the people who constructed it but between two construction stations. This was considered of very great advantage.

It was my experience that airsickness while crossing the English channel is not due to bad air. We had a window open. The trip was as rough as any I have made by boat, but it was completed much more quickly.

PROF. E. P. WARNER:—As to the airsickness I did not base my statement on personal experience. I did not make the Channel crossing in the air but know a number of people who did and some of them were very sick. In the case of one machine on test, the observer was an officer of the Royal Air Force. The pilot came in perfectly cheerful at the end of 2 or 3 hr. but the observer, shut in the little cabin, was very much knocked out. This indicated that the ventilation was poor.

MR. UPSON:—The man who is piloting the machine is responsible for its safety. He has no time to be sick.

PROFESSOR WARNER:—As a matter of fact, I am sure the airsickness was attributable to the fact that the machine was enclosed. There was perhaps something in the design that caused particularly bad ventilation. In regard to the separation of the builder and the operator, I will grant Mr. Upson's point in the case of the Zeppelin company, which controls several other organizations, and in connection with airships in general. The Zeppelin airship works is at Friederichshafen, and about 2 miles from its Berlin terminus; it produces the four-engine airplanes. It certainly is desirable that there should be the closest cooperation between the builder and the operator, but I believe there should be no connection in the case of airplane companies. If we divorce the two, we will throw on the designer the responsibility of meeting competition in the open market. Let us allow the operating man to run his service, and not get the finances of the two mixed up in trying to make the one support the other.

LADISLAS D'ORCY:—Is it not a fact that the report of

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the British committee on civil aerial transport stated that commercial aviation could not be operated on a profitable basis except through subsidy in one form or another?

PROFESSOR WARNER:—There is a report, issued during the spring of 1920, from a committee made up of ten very distinguished men appointed by the Air Ministry. They say that several important conclusions can be drawn from the evidence given. One is that the transportation of passengers and goods alike is apt to come forward spasmodically; that there does not seem to be any deep-seated confidence on the part of the public in these services. I think that has been overcome. The report of a minority of the committee states that it is not in favor of subsidizing any air company. The majority of the committee advocated a subsidy but this was no adopted.

ADRIAN VAN MUFFLING:—Alluding to lighthouses, just what is their appearance in daylight?

PROFESSOR WARNER:—They have ground-marks all along the route and they are painting the names of the towns all along these routes. Some of the lighthouses are of the form adopted for marine work, with a Fresnel lens directing the rays into the upper quadrants. That has not been altogether satisfactory, and it seemed that better results would be secured by using a searchlight. A single searchlight beam shot into the air can be seen at a distance of 40 miles. I am told that even above a bank of clouds the glow of a searchlight can be seen.

MR. UPSON:—It gives better results to play the searchlight beam around.

PROFESSOR WARNER:—Yes.

E. A. SPERRY:—The vertical high-intensity searchlight beams we furnished the Army can be thrown above the fourth layer of cloud. A beam has been seen at a distance of 130 miles when it is waved back and forth. These beams will probably constitute the great beacons for night flying. They are very powerful, the 60-in. giving a light of about *one and one-third billion* candle-

PROFESSOR WARNER:—Would that be practicable? Would it be a thing we could afford to run regularly?

MR. SPERRY:—A 60-in. beam has been seen probably farther round the earth's curvature than any light heretofore produced. It requires only 150 amp. at 74 volts, a positive carbon 5/8 in. in diameter and a negative carbon 7/16 in. in diameter. It produces 150,000 cp. raw light without a condenser or reflector.

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HIGHWAY-ROAD CONSTRUCTION

By W E Williams[1]

Stating that asphalt, brick and concrete-slab road-surfaces are the only pavements that have given satisfaction for automobile traffic, the author believes further that thus far the concrete-slab surface is the only one worthy of consideration for such traffic. He discusses the merits and demerits of these surfaces and includes an enumeration of the factors that combine to produce a thoroughly satisfactory road surface.

Passing to a detailed review of the bearing value of soils and the correction of road failures, the author presents data and illustrations in substantiation of his statements and follows this with a consideration of the reinforcing of a concrete road-slab with steel.

Regarding the ultimate highway, it is stated that a concrete-slab road, about 8 in. thick and of uniform depth across the road, perhaps with an increaseed thickness of integral supporting curb-block on the edges in some locations, is the type of road that should be built in this country, and reasons in support of this are given. The subject of impact is discussed and its meaning explained.

Only three road surfaces have given satisfaction for automobile traffic; asphalt, brick and concrete slabs. Thus far the concrete-slab surface is the only one worthy of consideration for such traffic. Many people think that the roadbed should be elastic and that the asphalt and the brick surfaces furnish elastic conditions. Experience has proved that an asphalt surface will not stand up under heavy truck traffic. The brick surface comes nearer to the desirability of the concrete-slab surface than the asphalt.

The idea that an asphaltic surface is necessary for the riding qualities and preservation of the vehicle is an old one; it has been threshed out in railroad service and other lines with the result that elasticity in a roadbed is found to have been a mistaken idea. The best roadbed is an absolutely solid one, with as straight a surface as can be obtained. One of the examples of an old theory in regard to elasticity is found in stamp mills that reduce ore. It was believed for generations that a stamp mill should be founded on a heavy timber grillage

[1]M.S.A.E.—Consulting engineer, Chicago.

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having masonry underneath, the timber furnishing, as it were, an elastic shock cushion for the stamp-rods. It appeared that, whenever these stamps were founded on solid masonry, the stamp-rods would crystallize and break. The builders of these mills specified in old days that their guarantee would not follow the mill unless it was founded on a timber grillage. This method was discarded by engineers in the copper country, who built heavy masonry foundations with the least possible elasticity and made the stamp-rods of steel. Then it was found that this type of stamp mill was better than one having an elastic timber-grillage base-construction. The stamp-rods did not crystallize and break when made of steel.

The road surface should be as nearly rigid as it is possible to make it. It is a mistake to make a road surface which is expected to bend under the movement of traffic, even in the least possible amount that is preventable; for in this way the road is destroyed. The asphalt-surface road, or a brick-surface road, must have a concrete base. The asphalt and brick surfaces aid the concrete base but slightly in sustaining beam loads, or in providing a wider distribution of the load over the surface soil or sub-base of the road; whereas, if the equivalent of the thickness of the asphalt and the brick, and particularly the cost of laying those materials, is expended in producing an extra thickness of the concrete slab, a stronger load-sustaining surface will be obtained than it is possible to get at the same cost with any supplementary facing such as asphalt or brick. It costs more to lay the asphalt or brick for a given depth than it does for the same depth of concrete. A brick surface is substantially 4 in. in depth and is supported by 4, 5 or 6 in. of concrete base, making a total depth of not less than from 8 to 10 in. The relative strength as a beam of that road surface is substantially limited to the thickness of the concrete underneath the brick, say 6 in. as a maximum. A concrete slab of the same relative depth as 4 in. of brick and 6 in. of concrete, would amount to 10 in. The relative load-sustaining capacity as a beam construction would be 36 for the brick surface, being the square of the depth of 6 in., which is the thickness of the concrete base; it would be 100 for the concrete slab, being the square of the depth of the concrete slab. Thus, both brick and asphalt have no chance of being competitors for service on a motor-

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truck highway. The concentrated loads placed upon the wheels when the heaviest trucks are considered run as high as from 4 to 8 tons under a single wheel. This is on an area perhaps not greater than ⅓ sq. ft. The crushing bearing value of the concrete at 3000 lb. per sq. in. is able to carry the load, but the bearing value for many subsoils is not.

FIG. 1—TYPICAL FAILURE OF A CONCRETE-SLAB ROAD

BEARING VALUE OF SOILS

From a standpoint of furnishing foundations for buildings, which are static loads instead of being vibratory, the bearing values of soils are rarely ever estimated for more than 5000 lb. or 2½ tons per sq. ft. for the best types of soil. For vibratory loads, such as the sub-bases of hard roads, an average bearing should not be taken at more than 1 ton or 2000 lb. per sq. ft. With the same soils and bad weather conditions 1000 lb. per sq. ft., or less, is all that the soil will stand. The moisture variations in sub-base soils for roads make bearing values appear fickle indeed, ranging from 2 to 10 lb. per sq. in. in some tests made on an Illinois road sub-base and thus ranging from 288 to 1440 lb. per sq. ft., so, the bearing value is illusive and is not safe at over 1000 lb. or less per sq. ft. in Illinois.

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FIG. 2—FIRST STAGES IN THE CRACKING OF A CONCRETE ROAD-SLAB

Solid rubber tires are rated to carry 800 to 900 lb. per lineal inch of width of tire, on the largest sizes. A 14-in. tire bearing 900 lb. per in. amounts to a total load of 12,600 lb., or 6½ tons under a single wheel. The heaviest makes of large trucks that are actually used often exceed that bearing load per wheel. This tire load of 12,600 lb., disregarding the excess often met with, must be supported by the sub-base of the roadway at the worst season of the year. This is when the ground is wet and the frost is coming out, a time that the sub-base should not be required to support a load of over 2000 lb. per sq. ft., or less; so, to take care of this 12,600 lb. on that wheel, the concrete slab should be able to distribute it over an area of at least 6 sq. ft.

If the wheel gets near the edge of the slab of the concrete, it amounts to making the slab transmit the load in a semi-circular area having a radius of 4 ft. On crossing an expansion joint or cross crack, the wheel load will then be carried, as it were, by the point or apex of a triangular section, making the concrete slab distribute its load from a point or apex of a right-angle corner over the area of 6 sq. ft. already mentioned, which would result in a right-angle triangle, or its equiva-

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lent of about 3½ sq. ft. on the side. Assuming that there is underneath this triangular slab a soil bearing of 2000 lb. per sq. ft., there will result strains along the hypothenuse side of this triangle on the extreme fibers of the concrete in tension of 380 lb. per sq. in. for 6½-in. slab and 250 lb. per sq. in. for 8-in. slab. At a soil bearing of 1000 lb. per sq. ft., the better average for bad weather conditions of subsoil, the maximum fiber stress for 6½-in. slab is about 600 lb. per sq. in. and for an 8-in. slab 400 lb. per sq. in. No concrete which is not reinforced will withstand these stresses. Good concrete in tension runs from 250 to 300 lb. per sq. in. Many slabs are seated so that there is a slight movement or vibration of the slab at every load that passes and, with heavy loads, this vibration packs down the subsoil until there is an actual void for a considerable distance underneath the slab. The slab then breaks and this is what occurs in most of the failures. The photographs shown in Figs. 1 to 4 are typical of just such breaks, which in our district have furnished the bulk of the failures in concrete roadways, and Table 1, in connection with Fig. 5, shows the stresses involved as already described.

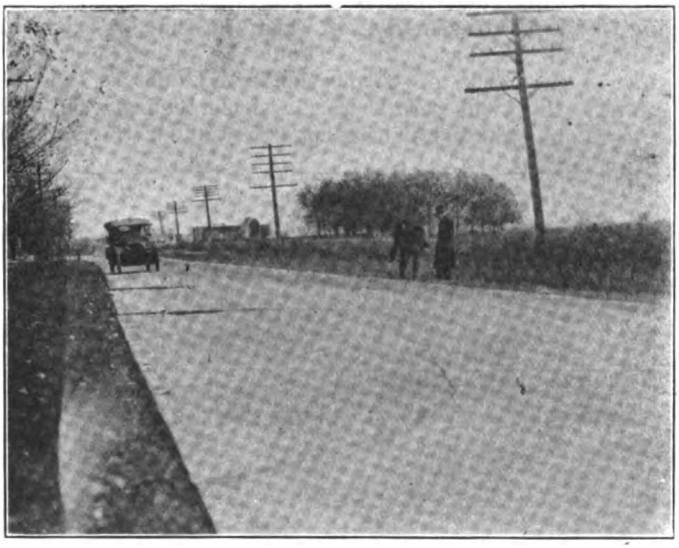

FIG. 3—VIEW OF AN ILLINOIS CONCRETE HIGHWAY SHOWING HOW THE SURFACE HAS CRACKED

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FIG. 4—AN EXAMPLE OF HOW CRACKING DIVIDES THE SURFACE INTO A SERIES OF TRIANGULAR SLABS

CORRECTING ROAD FAILURES

Many different remedies have been offered for correcting road failures. One of them is that on clay or aluvial-soil sub-bases there should be placed a cushion 3 or 4 in. thick, of porous material such as sand or cinders, that will permit the sub-base to drain out and remain in a more uniform condition under the varying

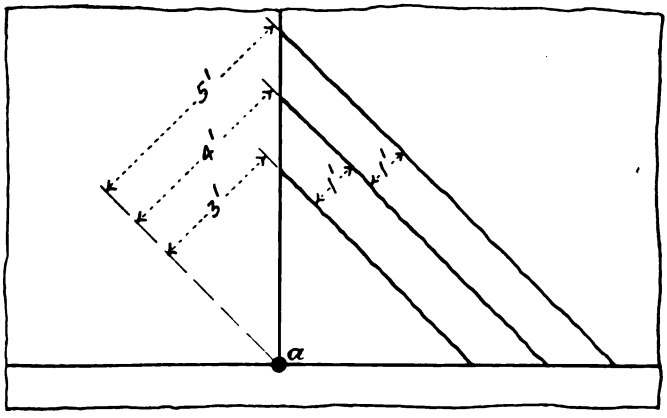

FIG. 5—STRESSES INVOLVED IN A TRIANGULAR SLAB

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TABLE 1—LOADS AND STRESSES ON TRIANGULAR CONCRETE SLABS[2]

			Pressure between Concrete and Subsoil			
			None		1,000 lb. per sq. ft.[3]	2,000 lb. per sq. ft.[3]
Load at *a*, Fig. 5, lb.	Length of Arm, ft.	Concrete Thickness, in.	Stress, lb. per sq. in.	Deflection, in.	Stress, lb. per sq. in.	Stress, lb. per sq. in.
9,600	3	6.5	680	0.054	468.0	2.56
	4	6.5	680	0.097	302.0	[4]
	5	6.5	680	0.151	90.0	[4]
	3	8.0	450	0.029	310.0	170
	4	8.0	450	0.052	200.0	[4]
	5	8.0	450	0.081	59.5	[4]
12,600	3	6.5	895	0.071	682.0	380
	4	6.5	895	0.127	516.0	[4]
	5	6.5	895	0.198	302.0	[4]
	3	8.0	590	0.038	450.0	250
	4	8.0	590	0.068	340.0	[4]
	5	8.0	590	0.106	200.0	[4]

[2]Modulus of elasticity equals 2,500,000 lb.

[3]Assuming that no deflection is necessary to obtain the 1000 lb. per sq. ft. pressure, the bending moment for 1000 lb. and for 2000 lb. per sq. ft. pressure between the concrete and the subsoil is reduced an amount equivalent to a load of 1000 lb. or 2,000 lb. per sq. ft. on the concrete, as the case may be, over that under the heading "None."

[4]Concrete at 2000 lb. per sq. ft. pressure would carry the load.

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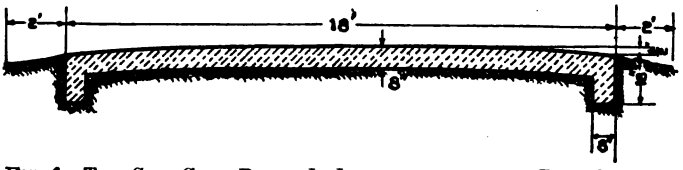

FIG. 6—THE SIDE CURB-BLOCK IS INTEGRAL WITH THE ROAD SURFACE

weather conditions. In some localities the sand sub-base seems to indicate that this is the correct thing to do. In Illinois, however, we have roads that have sand sub-bases that have cracked as badly after a time as the other bases did. It is my opinion that the cost of this sand should be expended in providing a thicker slab of concrete. A sand sub-base 3 in. thick might cost approximately the same as another inch in depth of concrete slab.

If the concrete slab is 6 in. thick and the sand base 3 in., by leaving off the sand base we might make the slab 7 in. The relative beam strength of the concrete slabs would then appear as 36 for the 6-in. and 49 for the 7-in. slab, a gain in strength for the 7-in. slab of one-third, measured in the value of a 6-in. slab. A slab 8 in. thick would represent a beam strength of 64 compared with a beam strength of 81 for a 9-in. slab. Here again more than a one-quarter increase in strength is

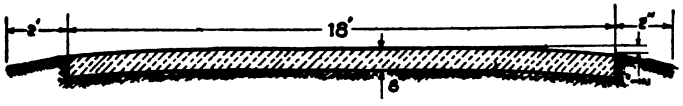

FIG. 7—A TYPICAL 8-IN. CONCRETE SLAB ROAD AS NOW BUILT

obtained by an extra 1 in. of depth. In some instances it is desirable to make the slab on the edges with a rib or a curb section extending down into the soil to stiffen the edges of the slab and shut out the excess moisture that runs over, seeps down under the base and softens the soil sub-base. This edge or under supporting curb block, when made an integral part of the slab itself, is a good investment in many cases. This feature is worthy of consideration for general adoption. It is illustrated in Fig. 6, which shows the side integral curb-block before mentioned that is the best form in my opinion.

Fig. 7 represents a typical 8-in. concrete-slab road as now built. A better road, in my opinion, is shown in

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Fig. 8, where the slab is divided along the middle of the road to let each side spring by itself under heavy loads. The upper view in Fig. 9 shows the provision for one longitudinal central drain, cared for by cross-drains at intervals. This is better construction than two side-drains. The lower view is better construction than that shown in Figs. 7 and 8, for it allows a central moistening of the sub-base as well as at the sides and provides for uniform settlement of each side slab. Fig. 10 is a suggestion for a steel-surface road having flat steel wheel-tracks 18 in. wide, imbedded in concrete slabs. The steel

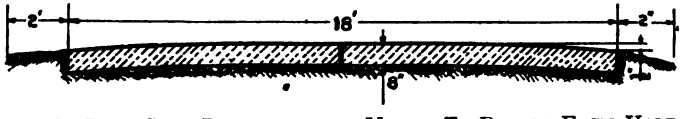

Fig. 8—Road Slab Divided at the Middle To Permit Each Half To Spring Separately under Heavy Loads

tracks are inverted channels and the concrete slabs are narrow and ballasted with broken stone, which permits the slabs to be surfaced up like a railroad track. The cost of this appears prohibitive, but one cannot tell what experience may lead to. Fig. 11 shows the trend of thought toward a steel-surface road.

Reinforcement

Reinforcing with steel in a concrete road slab is of doubtful value, except in special cases. If reinforcement is applied only sparingly it is of little or no value; in fact, I think it results in injury to the concrete. Reinforcing should be omitted unless sufficient steel is put in the top and bottom of the slab to permit the rein-

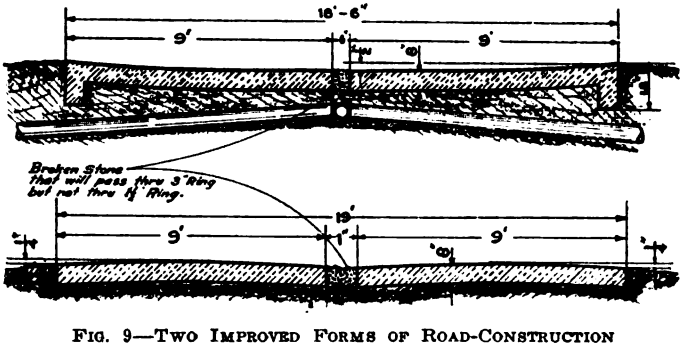

Fig. 9—Two Improved Forms of Road-Construction

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forcing to carry the load at low metal-fiber stresses, so that the stretch of the reinforcing under the maximum fiber stresses will not exceed the elastic limit of the concrete. If, however, the reinforcing is strained up to permissible limits for the steel, the stretch in the steel before those limits are reached breaks the reinforcing free of its bond in the concrete and the latter will crack.

There are certain places where it is well known in advance that the concrete slab will be required to act as a beam; for example, where an embankment is merged onto a solid abutment and it is certain that the soil or sub-base underneath the slab will sag away from the solid abutment. Reinforcing should be placed then on the bottom side of the slab, making this last slab a bridge from the mudbank to the solid masonry abutment. In such cases sufficient reinforcing can be used to make this slab safe. The cost of reinforcing, no matter how sparingly it is used in a road slab, can be better expended generally in providing a deeper concrete slab. Thus, the benefit of the square of the depth in the increased depth of the slab is obtained, making a better road than is obtained for the same money with reinforcing. Working this out in figures of cost and strength of slab will show that this conclusion is correct.

The Ultimate Highway

A concrete-slab road, about 8 in. thick and of a uniform depth across the road, perhaps with an increased thickness integral supporting curb-block on the edges in some locations, is the type of road that should be built in this country. If this road will not stand up, and it appears that it will not carry the maximum strains required by the heaviest trucks, then those heavy trucks must be denied the use of the roads. By roads, I mean country roads. The city pavements are in a different situation, because they extend from curb to curb and no water is expected to seep through and soften the sub-bases. The heavy traffic does not run generally on the edges of the slab but over the body thereof; so, owing to the protected sub-base, heavier loads can be carried on city pavements than can be expected to be carried on a country road. The needs of the automobile world and the general welfare of the country are that we should have the greatest amount of hard roads possible, to be obtained in the shortest space of time and with the least expense. It is better for the roads to be limited to the use of vehicles that will not

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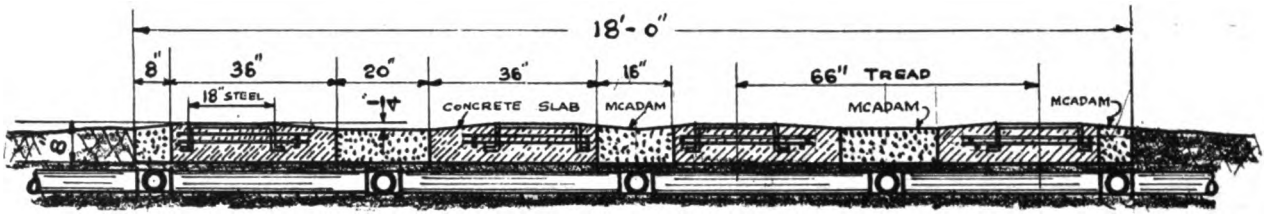

FIG. 10—A FORM OF ROAD CONSTRUCTION IN WHICH INVERTED STEEL CHANNELS ARE EMPLOYED TO FORM THE WHEEL TRACKS

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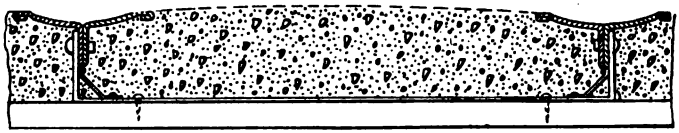

FIG. 11—THE TREND IN STEEL-SURFACE ROAD-CONSTRUCTION

break down the average standard road than to be required to build a road for our excessively heavy trucks.

When a road is built for the maximum load that the heaviest trucks are known to carry, then we will have limited to only a small mileage the ability of the country to furnish that type of road; whereas, with the other types of road, the mileage can be increased so that it will increase the use of automotive vehicles and furnish the demand for vehicles that the manufacturers want, even if in a few instances there is some hardship to the builders of some types of vehicle. In my opinion, the automobile vehicle world will profit by laws that prohibit anything above a 5-ton load and force trailers to take care of the heavy-weight loads. The maximum tire load of the maximum truck load is the factor to be considered, and not the weight per inch of tire. The concrete surface will withstand more per inch than will any rubber tire. It is the beam strength of the concrete slab that counts. In other words, the amount of load per square foot of area on the sub-base which the slab must distribute is what we have to look after.

IMPACT

Impact is much discussed and is likewise misunderstood. If the road and the tires are smooth and the road has no offsets, the greater the speed of the load over the road is, the less the damage will be. Gravity is a time factor. We remember that as boys we skated over thin ice. A speed of 10 m.p.h. is 14.66 ft. per sec.; at 20 m.p.h. it is 29.33 ft. per sec. Thus the force of gravity on the slab for a given second at 10 m.p.h. is spent on 14.66 ft. of length of the slab and at 20 m.p.h. on 29.33 ft.; so, with smooth surfaces, the speed is a secondary factor of destruction. With bumps in the road, tire speed is a serious factor of destruction. A brick surface cannot be commercially laid without having an infinite number of small offsets that produce impact remaining in its surface.

A speed of 10 m.p.h. is about 1/15 sec. and one of 20 m.p.h. about 1/30 sec. to 1 ft. of travel on the road.

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The acceleration of gravity will cause a drop of 0.87 in. in 1/15 sec. and 0.22 in. in 1/30 sec. Omitting the action of the springs, a wheel will travel downward off of an abrupt shoulder less than 1 in. in 1 ft. of road travel at 10 m.p.h. and less than ¼ in. at 20 m.p.h. However, the springs of a vehicle counteract this and produce impact of the wheels on the road in much shorter distances. Offsets of any kind are serious factors of impact and destruction.

I repeat that the money available should be made to build the greatest mileage of road that will induce the use of the largest number of automotive vehicles, even at the sacrifice of the heaviest ones. [The discussion of this paper is printed on page 35.]

THE NATURE OF FLAME MOVEMENT IN A CLOSED CYLINDER

By C A Woodbury[1] H A Lewis[2] and A T Canby[3]

The nature of flame propagation in an automobile engine cylinder has, for some time, been the subject of much discussion and speculation. However, very little experimental work has been done on flame movement in closed cylinders with a view to applying the knowledge directly to the internal-combustion engine.

It has become recognized that knocking is one great difficulty which attends the use of the higher-boiling paraffin hydrocarbons, such as kerosene, and that knocking is one of the major difficulties to be overcome in designing higher-compression and hence more efficient engines. It was desirable, therefore, to determine, if possible, the nature and cause of the so-called fuel knock in an internal-combustion engine.

The work described in this paper was undertaken to determine the characteristic flame movement of these various fuels and the physical and chemical properties which influence this flame propagation. The scope of the work is specified and the arrangement of the apparatus for measuring flame propagation is illustrated and described. Flame movement at normal temperature and pressure was then investigated, the

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results obtained are shown in charts and a table and these are commented upon in detail. The influences of turbulence and of temperature and pressure on flame propagation are treated in like manner, followed by a lengthy discussion of autoignition and the nature of fuel knock, which also is illustrated.

The nature of flame propagation in an automobile engine cylinder has, for some time, been the subject of much discussion and speculation. However, very little experimental work has been done on flame movement in closed cylinders with the view of applying the knowledge directly to the internal-combustion engine. Recently automobile builders and others have seen the production of automobiles, trucks and tractors increase at a rate out of all proportion to the increase in the production of the vital fuel, gasoline. With the recognition of this attention was turned to the possibilities of (*a*) using other fuels such as kerosene, benzine, and alcohol and (*b*) increasing the efficiency of the engine when using the existing standard fuel. To accomplish either of these ends information on the flame propagation characteristic of each of these fuels was essential.

It has become very generally recognized that there is one great difficulty; namely, "knocking" which attends the use of higher-boiling paraffin hydrocarbons, such as kerosene, and that "knocking" is one of the major difficulties to be overcome in designing higher-compression, and hence more-efficient, engines. It was desirable, therefore, to determine if possible the nature and cause of fuel knock. The work described in this paper was undertaken to determine the characteristic flame movement of these various fuels and the physical and chemical properties which influence this flame propagation.

Scope of Work.

The program which was originally decided upon assumed that a knowledge of flame movement at atmospheric temperature and pressure should be studied first. It was then proposed to determine

(1) The influence of turbulence or movement of the gas at the moment of ignition
(2) The influence of temperature
(3) The influence of pressure or density
(4) The influence of the shape of the explosion chamber
(5) The influence of the position and number of ignition points, together with the importance of the intensity of the ignition

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It was assumed that a clear understanding of the above factors as affecting one fuel should be gained before attempting a comparison of the different fuels. To simplify the work a permanent gas, acetylene, was selected for the development of methods of testing and for preliminary experiments. The experiments outlined in this paper represent only a preliminary survey of the factors included in the above outline. It is hoped that future work will give more exact information regarding the effect of these several variables. In addition to the experimental work on flame propagation a comprehensive study of the literature bearing on the subject has been made. Considerable attention is given in this paper to the discussion of the results so found.

After a general survey of the methods of measuring flame propagation which have been used by various investigators, it was decided to use the photographic method chiefly for the reason that, if successful, it would disclose the rate and character of the movement of the flame at any point over the entire exposed distance of travel. To eliminate as many variables as possible in preliminary work a cylinder of constant volume without moving piston was chosen for the explosion chamber.

Naturally many difficulties were encountered in the development of the apparatus. Chief among these were (*a*) lack of sufficient light from the flame at all times to reproduce itself properly on the film and (*b*) the construction of a gas-tight seal around the window of the explosion cylinder. The apparatus and method at its present stage of development are essentially as follows:

The explosion chamber at the right of Fig. 1 is a cylinder 4 in. in diameter and 12 in. long, inside measurements, provided with a ¾-in. glass rod extending the entire length as a window. High-pressure needle-valves are inserted in the top and bottom of the cylinder for introducing the gas charge and sweeping out the products of combustion. The gas is ignited by a standard spark-plug in the center of the lower end of the cylinder. A Midgley pressure element[3] is inserted in the top of the cylinder, the beam of light from the mirror of the pressure indicator being focused on a wax paper screen and reproduced on a film on the upper of two rotating drums. The light from the flame in the cylinder passes through a camera lens to another film on the lower rotating drum. The two drums are mounted on the same shaft which is driven by

[3] See TRANSACTIONS, vol. 15, part 2, p. 667.

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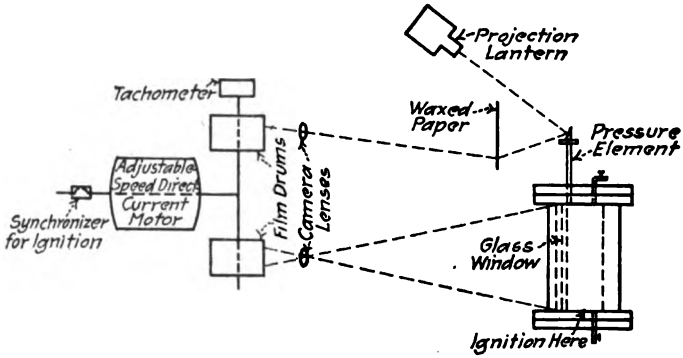

FIG. 1—ARRANGEMENT OF APPARATUS EMPLOYED FOR MEASURING FLAME PROPAGATION

an adjustable-speed direct-current motor so that drum speeds of from 100 to 4000 r.p.m. can be obtained. The speed is measured by a combined revolution counter and stop-watch mounted on the end of the shaft. Ignition of the gas charge is synchronized with definite needle-points on the film drum through a special sparking device on the rear of the driving motor. The apparatus thus gives a direct measurement and comparison of the rates of flame movement and pressure development from a definite ignition point. The fastest film on the market was inadequate for the purpose at hand. It was known from the work of the Bureau of Chemistry that great possibilities lay in the use of the so-called photo-sensitizing dyes for increasing the sensitiveness of emulsion to light of long wave-length. After consultation with the Bureau pinacyanol was selected and used very successfully.

In the course of the development of this apparatus, acetylene-air mixtures were exploded because of the high actinic properties of the flame. During this development period results were obtained on the nature of the flame movement at atmospheric temperature and pressure and some preliminary experiments carried out on the influence of turbulence, temperature, and pressure. In the experiments on temperature and pressure difficulties were first encountered in attempting to make the cylinder gas-tight around the window. The Midgley pressure element leaked due to the length of time required for charging the cylinder before ignition and was used only to a limited extent. As soon as these difficulties were overcome a few experiments were carried out on the combined in-

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fluence of high temperature and pressure using ether as a fuel, and on the influence of temperature on the tendency of mixtures of acetylene, oxygen and nitrogen to detonate.

Flame Movement at Normal Temperature and Pressure

Previous investigators of the nature of flame movement at ordinary temperatures and pressures in closed vessels have confined their observations almost entirely to pressure and temperature measurements rather than to flame propagation. Although little information is available concerning the actual flame movements, the rate of flame propagation is indicated with fair accuracy by the rate of pressure development within the explosion bomb, and on this basis very many data have been collected. The point of agreement between the rate of flame propagation and development of pressure accepted by all investigators is that the instant of total inflammation of the gas concurs with the instant of maximum pressure. This fact is substantiated by the experiments of R. V. Wheeler[4] in which close agreement was shown between the rates of flame propagation of various mixtures of methane and air when calculated from actual measurements of the rate of flame movement and from the period required for the development of maximum pressure in two spherical bombs of different capacity.

Early investigators assumed that the instant of ignition coincided with the first appearance of pressure on the indicator or gage. Bairstow and Alexander[5] however have shown that this was not the case, and that after ignition an appreciable period of time elapses before a pressure record can be obtained. Experiments by J. D. Morgan[6] indicate that the inflammation of a gaseous mixture is practically instantaneous with the passage of the igniting spark. It may, therefore, be concluded that the interval of time between ignition and the appearance of pressure is due to a lag in the indicators, or to cooling effect of the base and walls of the vessel. R. V. Wheeler[4] has studied this period using various mixtures of methane and air ignited at the center of spherical bombs and has calculated that approximately one-fifth of the total volume of gas is inflamed before pressure is first recorded.

In our experiments at atmospheric temperature and

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[4]See *Journal of the Chemical Society* (England), vol. 113, p. 840.
[5]See *Proceedings of the Royal Society of London*, vol. 76A, p. 340.
[6]See *Engineering*, Oct. 24, 1919, p. 535.

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pressure, mixtures of acetylene and air varying from 5 to 20 per cent of acetylene were exploded in the cylinder and the movement of the flame photographed. A general idea of the velocities of flame movement attained with these mixtures can be obtained from the results given in Table 1.

TABLE 1 —VELOCITIES OF FLAME MOVEMENT IN AIR-ACETYLENE MIXTURES

Composition of Mixture		Velocities Attained			
		Maximum		Average	
Acetylene, per cent	Air, per cent	Meters per sec.	Ft. per sec.	Meters per sec.	Ft. per sec.
5	95	9.10	29.86	4.05	13.29
6	94	.....	.....	6.05	19.85
8	92	38.00	124.67	12.50	41.01
10	90	25.00	82.02	15.00	49.21
15	85	20.80	91.86	8.10	26.57
20	80	9.20	36.09	4.00	13.12

As disclosed by previous investigators, the velocity was relatively low for lean and for rich mixtures showing the maximum for the mixtures containing from 8 to 10 per cent of acetylene.

We are not, however, so concerned with the actual velocities of flame movement as we are with the nature of the movement. Typical photographs of the flame movement for the 10-per cent acetylene mixture and for the slow mixture, such as the 20-per cent, are reproduced in Figs. 2 and 3 respectively. In these photographs the film should be considered as moving from right to left and the flame from the bottom to the top. The exceedingly slow initial movement of the flame followed by gradual acceleration is apparent. After the flame has traveled approximately two-thirds the length of the cylinder it suddenly stops. The movement is soon resumed, however, and the flame proceeds slowly to the top of the bomb.

In the case of the 10-per cent mixture there are successions of alternate dark and light vertical bands in the secondary burning period which first become perceptible at the point at which the flame-front is arrested. This is also true with the mixtures which gave relatively high velocities. These bands have a slight pitch apparently indicating a vibration with the approximate velocity of sound at the temperature. It is notable, however, with

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FIG. 2—PHOTOGRAPH OF THE FLAME MOVEMENT IN A MIXTURE COMPOSED OF 10 PER CENT OF ACETYLENE AND 90 PER CENT OF AIR HAVING AN INITIAL TEMPERATURE OF 25 DEG. CENT. (77 DEG. FAHR.), AND A PRESSURE OF 1 ATMOSPHERE

mixtures of low velocity, for example, 20 per cent of acetylene, that these vibrations are not present.

One naturally is particularly interested in why the flame comes to rest after traveling a certain distance; also what is responsible for the vibrations exhibited in the relatively fast mixtures. Before offering an explanation of these phenomena, it is first necessary to consider the rate of pressure development in these experiments as compared with the rate of flame movement.

It will be noted from a comparison of Figs. 4 and 5 that the curves showing the flame movement and the pressure development have the same general form, and that there is an arrest in the pressure development corresponding to the arrest in the flame movement. The time in Fig. 5 is calculated from the point of initial pressure and not from ignition of the charge. Fig. 6, giving the time relations from the ignition of the charge, shows that no pressure was recorded until the flame had traveled approximately 25 per cent of the length of the bomb. This is in agreement with the findings of previous investigators. It will also be noticed that the arrest in the pressure development occurred at approximately the same time as the arrest in the flame movement. The time of maximum pressure coincides with the time of total inflammation, as had been reported by previous investigators.

FIG. 3—PHOTOGRAPH OF THE FLAME MOVEMENT IN A MIXTURE COMPOSED OF 20 PER CENT OF ACETYLENE AND 80 PER CENT OF AIR HAVING AN INITIAL TEMPERATURE OF 25 DEG. CENT. (77 DEG. FAHR.) AND A PRESSURE OF 1 ATMOSPHERE

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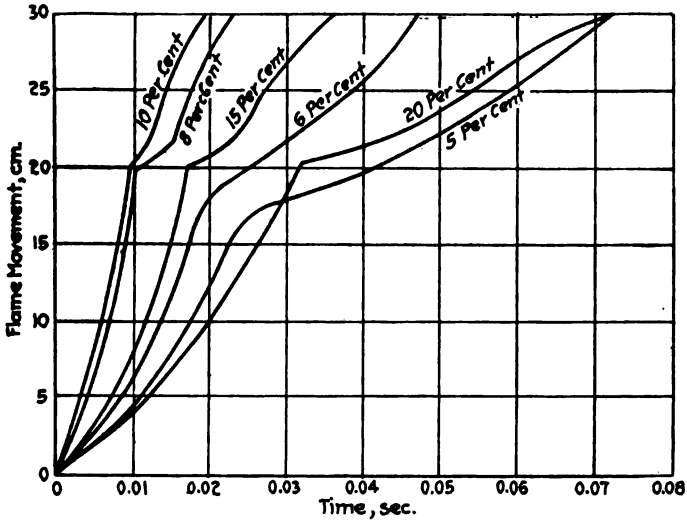

FIG. 4—FLAME MOVEMENT IN MIXTURES CONTAINING VARYING PERCENTAGES OF ACETYLENE

Fig. 6 shows also that at the time of the flame and pressure arrests the flame has propagated two-thirds of the length of the bomb whereas only one-quarter of the

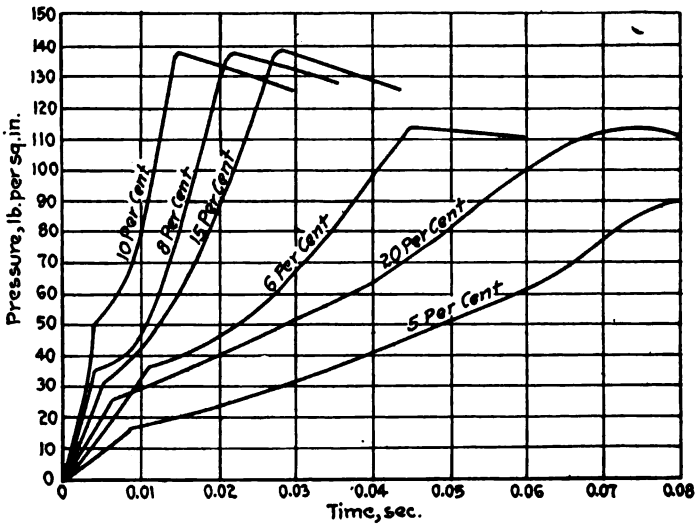

FIG. 5—CURVES OF PRESSURE DEVELOPMENT IN MIXTURES CONTAINING VARYING PERCENTAGES OF ACETYLENE

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total pressure has been developed, and that after the arrest the flame in traveling a comparatively short distance produced a very much greater increase in pressure. This is due, it is felt, to the fact that during the burning the expansion of the hot gases behind the flame pushes the flame-front forward and compresses the unburned gas ahead of the flame-front. Thus, in its propagation the flame is continually entering a gas of higher density which, when burned, naturally produces a greater increment in pressure.

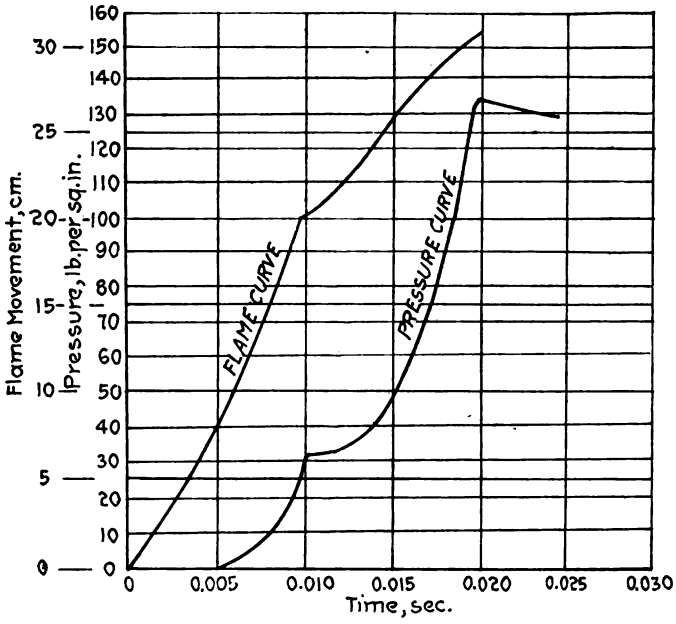

FIG. 6—CURVES OF FLAME MOVEMENT AND PRESSURE DEVELOPMENT IN A MIXTURE COMPOSED OF 10 PER CENT OF ACETYLENE AND 90 PER CENT OF AIR HAVING AN INITIAL TEMPERATURE OF 25 DEG. CENT. (77 DEG. FAHR.) AND A PRESSURE OF 1 ATMOSPHERE

This brings us to a new factor which probably plays a very important part in determining the rate of flame movement in closed cylinders.

According to Haward and Sastry[7], the rate of flame propagation during the so-called uniform movement period for an 8.9-per cent mixture of acetylene with air is

[7]See *Journal of the Chemical Society* (England), vol. 111, p. 841; vol. 116, p. 578.

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approximately 3.12 meters per sec. (10.24 ft. per sec.). This figure applies to experiments where the influence of pressure behind the flame-front did not exist. In our experiments in a closed cylinder mentioned above, an 8-per cent acetylene-air mixture during the uniform movement period attained a velocity of 38 meters per sec. (124.68 ft. per sec.) or 12 times that reported by Haward and Sastry. Apparently the expansion of the hot gases behind the flame-front exerted a great effect upon the rate of propagation. It is felt that this factor of expansion of the burned gases is of great importance in the consideration of the flame movement in closed cylinders.

With a realization of the characteristic nature of the pressure development ahead of the flame-front and the effect of the expanding burned gases it is possible to present an explanation of the flame arrest and the vibrations exhibited by relatively fast-burning mixtures. So far as has been determined, Dixon[8] was the first investigator to learn that in a closed tube flame does not travel smoothly through the entire column of gas, and that after traveling for some distance it practically stops as if struck by or striking something. Dixon holds the view that this flame arrest is due to the sound wave which travels from the sparking point at the bottom of the bomb to the top of the bomb, rebounds and strikes the flame-front. It is our opinion that these waves are produced by the arrest of the flame rather than being the cause of the arrest. In experiments to be mentioned later, in which turbulence was introduced into the bomb, practically no vibrations were apparent, due, it is felt, to the fact that the turbulence prevented the sharp arrest of the flame movement. Furthermore, it will be noticed in Figs. 2 and 3 that vibrations were present with the 10-per cent gas and absent with the 20-per cent gas, due presumably to the great difference in the sharpness of the arrest. The igniting spark was of the same intensity in all cases. Dixon's own photographs show that vibrations are not present except when there is flame arrest.

It is our theory that it is the high density of the gases ahead of the flame-front which arrests the forward movement of the flame. Just why the flame stoppage is sudden rather than a gradual slowing down, as the pressure accumulates ahead of the flame-front, is not wholly understood at this time. It is evident that during the entire travel of the flame, the gases approach a state of pressure

[8]See *Journal of the Chemical Society* (England), vol. 99, p. 594.

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equilibrium throughout the cylinder and the attainment of this equilibrium is hindered by the fact that the gases are not perfectly elastic. It has been previously shown that the flame-ront is pushed forward by the expansion of the burned gases and that the unburned gases are compressed to a high density at the same time. Obviously a point can be reached at which the pressure due to the temperature behind the flame is equalled by the pressure due to the density ahead of the flame. At that point the flame-front is no longer pushed forward; the propagation is arrested.

Furthermore, when such a point is reached, any burning of gas at the flame-front will exert its pressure equally in both directions; that is, ahead and behind the flame-front. The arrest in the flame usually occurs after about two-thirds the distance from ignition to the top of the cylinder has been traversed; the volume of the burned gas is then about twice that of the unburned gas. Applying equal pressure to these two unequal volumes obviously causes a greater linear contraction in the larger volume, or the burned gas. A recession of the flame-front would be expected under such conditions. In some fast-burning mixtures the flame-front does recede immediately after the arrest. After the arrest or recession of the flame-front, the forward movement is resumed, and a high density again built up ahead of the flame. This cycle of alternate arrest and resumption of the flame movement causes, in our opinion, the vibrations in the burning gases. It is recognized that other factors, such as the temperature and its effect on the elasticity of the gases, and the actual momentum of the forward moving flame, affect the arrest in the flame-front. It is felt, however, that high-density gas ahead of the flame-front is the most important influence.

Influence of Turbulence

The decided increase in the rate of flame propagation due to mechanical agitation of the gaseous mixture was first noted by Schloesing and de Mondesis[9] in 1864, and was described by Mallard and Le Chatelier. This information was apparently forgotten until Clerk and Hopkinson's[10] investigation of 1912. Since that time numerous investigators[11] have studied turbulence, establishing that the

[9]See *Annales des Mines*, Series 8, vol. 4, p. 298.
[10]See *Engineering*, July 11, 1913, p. 61.
[11]See Report of the British Association for the Advancement of Science for 1912, p. 201, and the *Journal of the Chemical Society* (England), vol. 115, p. 181.

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speed of burn is increased but the ignition rendered more difficult by agitating the gases.

Some very interesting results have just been published by Mason and Wheeler[12]. A tube 2.15 cm. (0.83 in.) in diameter and 220 cm. (85.53 in.) long was fixed horizontally. Streams of methane and air could be passed at different speeds along the tube, both ends of which were open. The mixtures were ignited electrically at a point 26 cm. (10.24 in.) from one end of the tube and the speeds of the flames were measured by screen wires, the first screen wire being 50 cm. (19.69 in.) from the point of ignition. A mixture containing 6.35 per cent of methane was used and the results given in Table 2 obtained.

TABLE 2.—FLAME SPEEDS IN AIR AND METHANE

Speed of Current of Air and Methane		Speed of Flame	
Cm. per sec.	In. per sec.	Cm. per sec.	In. per sec.
Nil	Nil	287	112.99
23	9.06	582	229.13
43	16.93	952	374.80
75	29.53	1,527	601.18

These results show that a comparatively gentle movement of the mixture as represented by a speed of 23 cm. per sec. (9.06 in. per sec.) nearly doubles the speed of the flame.

In our experiments a study was made of the effect of turbulence at atmospheric temperature and pressure. This study was on 10, 15 and 20-per cent acetylene-air mixtures. Varying degrees of turbulence were obtained by rotating a fan at different speeds, this fan being placed within the bomb at a point approximately equidistant from the two ends. Tests were made first with the fan at rest and then revolving at speeds of 1100, 2200, 3300 and 4400 r.p.m. Typical photographs are shown in Figs. 7 and 8, the former with the fan present but not revolving, and the latter with the fan revolving at 3300 r.p.m. These should be compared with Fig. 2 which was made without the fan being present.

An interesting point to be noted in comparing Figs. 2 and 7 is that the mere presence of the fan changes the

[12]See *Journal of the Chemical Society* (England), vol. 119, p. 578.

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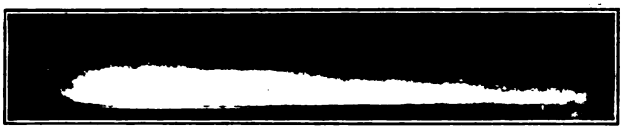

FIG. 7—PHOTOGRAPH OF FLAME MOVEMENT IN A MIXTURE COMPOSED OF 10 PER CENT OF ACETYLENE AND 90 PER CENT OF AIR HAVING AN INITIAL TEMPERATURE OF 25 DEG. CENT. (77 DEG. FAHR.) AND A PRESSURE OF 1 ATMOSPHERE

When This Photograph Was Taken the Fan Which Was Placed within the Bomb to Produce Turbulence Was Not Rotating. This Illustration Should Be Compared with Fig. 2 Which Was Taken Before the Fan Was Placed in the Bomb

character of the flame arrest. There is a decrease in rate, but this is gradual rather than sudden.

In all of the experiments with the fan revolving, the nature of the flame movement was similar to that shown in Fig 8. It was apparent that although turbulence seemed to interfere with the accumulation of the pressure ahead of the flame-front thereby eliminating a sudden arrest and although the distance of smooth accelerated flame-travel was increased with increase in turbulence (See Fig. 9), nevertheless the flame movement did slow down in all cases as it approached the top of the bomb. It is recognized, however, that still greater turbulence than obtained in our experiments, or other types of gas agitation than that used, might have given continually accelerating rates of propagation through the entire column of gas.

An idea of the effect of turbulence on the actual speed of the flame movement is given in Table 3. These results show that the slower the rate of propagation in the mixture without turbulence, the greater the effect of turbulence on that rate.

Although the results obtained to date are of a preliminary nature, they indicate the tremendous influence of

FIG. 8—FLAME MOVEMENT IN A MIXTURE COMPOSED OF 10 PER CENT OF ACETYLENE AND 90 PER CENT OF AIR HAVING AN INITIAL TEMPERATURE OF 25 DEG. CENT. (77 DEG. FAHR.) AND A PRESSURE OF 1 ATMOSPHERE

When This Photograph Was Taken the Fan Which Was Placed in the Bomb to Produce Turbulence Was Revolving at 3300 R.P.M.

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TABLE 3—INFLUENCE OF TURBULENCE ON THE VELOCITY OF FLAME MOVEMENT IN ACETYLENE-AIR MIXTURES

Acetylene, per cent / Air, per cent	Composition of Mixture					
	10 / 90		15 / 85		20 / 80	
Speed of Fan, r. p. m.	Average Velocity					
	Meters per sec.	Ft. per sec.	Meters per sec.	Ft. per sec.	Meters per sec.	Ft. per sec.
At Rest	15.0	49.21	8.1	26.57	4.0	13.12
1,100	21.3	69.88	17.5	57.41	6.9	22.64
2,200	25.0	82.02	19.8	64.96	10.7	35.11
3,350	29.6	97.11	24.5	80.38	14.9	48.88
4,400	38.9	127.62	30.4	99.74	20.6	67.63

turbulence on the rate of flame propagation and the important relation which a complete knowledge of the nature and direction of the flow of gases bears to the design of internal-combustion engines.

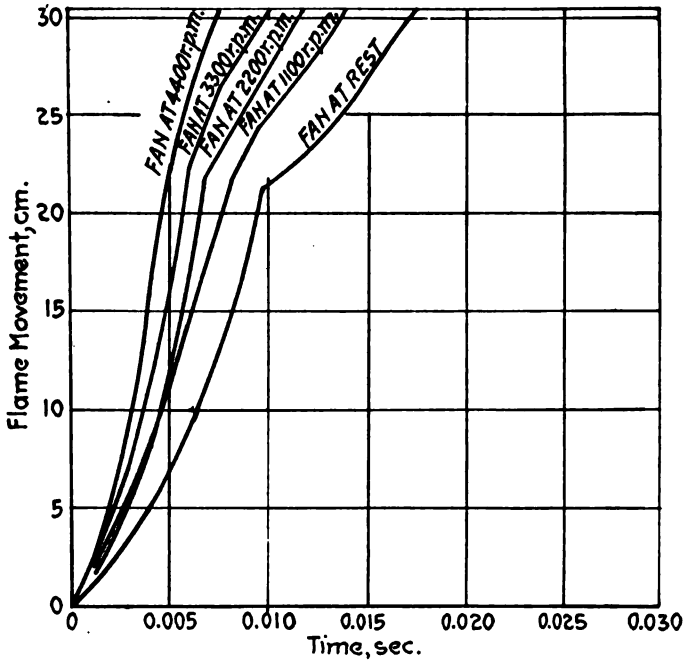

FIG. 9—TURBULENCE EFFECTS ON A MIXTURE COMPOSED OF 10 PER CENT OF ACETYLENE AND 90 PER CENT OF AIR HAVING AN INITIAL TEMPERATURE OF 25 DEG. CENT. (77 DEG. FAHR.) AND A PRESSURE OF 1 ATMOSPHERE PRODUCED BY ROTATING THE PRESSURE FAN AT VARIOUS SPEEDS

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Influence of Temperature and Pressure on Propagation

Several investigators have made statements which indicate that increased initial temperatures increase the rate of flame propagation and it seems entirely reasonable to expect such behavior. However, the study of temperature effect has been greatly neglected in the past and few actual experimental data are available. Our work on increased temperature at constant pressure was carried out on mixtures varying from 8 to 20 per cent of acetylene in air at temperatures from 25 to 125 deg. cent. (77 to 257 deg. fahr.). With a 10-per cent acetylene-air mixture at 25 deg. cent. (77 deg. fahr.) an average velocity of 15 meters per sec. (49.21 ft. per sec.) was obtained; at 50 deg. cent. (122 deg. fahr.), 12.2 meters per sec. (40.03 ft. per sec.); at 70 deg. cent. (158 deg. fahr.), 10.8 meters per sec. (35.43 ft. per sec.); and at 80 deg. cent. (176 deg. fahr.), 10.35 meters per sec. (33.96 ft. per sec.). The maximum velocity attained was practically unchanged over this range of temperature. With richer mixtures containing 15 and 20 per cent of acetylene there was an apparent increase in rate of propagation with increase of temperature from 25 to 75 deg. cent. (77 to 167 deg. fahr.), and then a decrease in rate on further rise to 125 deg. cent. (257 deg. fahr.). Difficulty was encountered in obtaining pictures at the higher temperatures, as the lowered density of the gas greatly diminished the available amount of light. It is possible that this decrease in density of the gas by dispersion may have counteracted any increase in rate of propagation due to increase in initial temperature. The results obtained indicated that increased temperature produced little effect upon the rate of flame propagation. The investigation was not carried over a sufficiently wide range of conditions to warrant a final conclusion, however.

The effect of initial pressure on the rate of flame propagation may be more easily studied than that of initial temperature, for pressure variations may be made independent of temperature changes. The results available are, therefore, more definite. Very high initial pressure apparently produces no material increase in the rate of flame propagation. This is brought out by the work of Peteval described by Dugald Clerk.[13] In his experiments Peteval measured the rate of pressure develop-

[13]See the Gas, Petrol and Oil Engine by Dugald Clerk, vol. 1, p. 166.

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ment and, therefore, indirectly the rate of flame propagation of a mixture of coal gas and air compressed to an initial pressure of 1100 lb. per sq. in. It was found that the time required to attain maximum pressure was almost identical with that required by the same mixture when fired at atmospheric pressure.

In our attempts to study the effect of pressure on the rate of flame propagation, considerable difficulty was encountered in keeping the bomb gas-tight, and the results cannot be presented as conclusive evidence at this time. The results obtained on various mixtures of acetylene and air under initial pressures of from one to four atmospheres, indicated that with each gas mixture the rate of propagation increases with an increase in the initial pressure up to a critical density and that with any further increase in the pressure above that critical value no increase in the rate of propagation is obtained. The critical density in most cases is two to three atmospheres. Similar results, described below, are reported by Dixon on the effect of pressure on the velocity of the detonation wave. A consideration of the information at hand indicates that increased initial pressure does not materially affect the rate of flame propagation. It must be understood, of course, that these statements apply only to the effect of temperature and pressure on the rate of propagation during any particular phase of flame travel; for it is well known that the inflammability of any mixture and the nature of the propagation of the flame through a mixture is greatly influenced by any increase in the temperature and the pressure.

If our assumptions that temperature and pressure do not materially affect the rate of flame propagation are correct, then consideration must be given to the effect of these factors on the nature of the propagation to find an explanation for certain phenomena which occur in an internal-combustion engine and which are known to be associated closely with the pressure and temperature conditions existing in the engine. The normal propagation of the flame through the combustion-chamber might be influenced in various ways, as for example, by the development of the detonation wave or by the appearance of autoignition in the unburned gases ahead of the flame-front.

In a study of fixed gases such as acetylene, hydrogen, carbon bisulphide and cyanogen, Dixon[14] has established

[14]See the *Philosophical Transactions of the Royal Society of London*, vol. 200, p. 315.

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that a considerable distance of flame travel from ignition is necessary before the development of a detonation wave, and that this necessary distance depends upon the fuel, and upon the ratio of fuel to oxygen. For example, the acetylene burn accelerates to detonation in a much shorter distance than does that of hydrogen. Dixon[15] has recently disclosed that he has been studying the development of the detonation wave in mixtures of liquid fuels, such as ether, alcohol, pentane and benzine, in air. No details of the work are given, but ether and alcohol are classed together as able to just propagate detonation, and benzine and pentane are classed together as unable to accelerate to detonation at atmospheric temperature and pressure.

It has been found that the velocity of the detonation wave is decreased by increase in temperature[16] from 25 to 100 deg. cent. (77 to 212 deg. fahr.). A study of both reduced and increased initial-pressures has shown that for each gas mixture a critical pressure exists, usually two or three atmospheres absolute, below which the detonation velocity increases with any increase in the pressure, but above which the velocity is practically constant and independent of any pressure increase.

A search of the literature, however, reveals no definite information concerning the influence of various physical factors, such as temperature and pressure, on the development of detonation in the case of any particular fuel-air mixture.

Our work was therefore confined to the identification of the detonation wave as determined by our apparatus and a brief study of the effect of the composition of the mixture of acetylene, oxygen and nitrogen, and of the influence of an increased initial-temperature and pressure, on the tendency to develop detonation. An attempt was also made to develop detonation in the case of a badly knocking fuel such as ether, by igniting at a high temperature and pressure. No detonation was obtained in this case and the results are therefore discussed under the subject of autoignition below.

Preliminary work on acetylene-air mixtures showed that the detonation wave could not be set up in the 12-in. cylinder by igniting at atmospheric temperature and pressure. The mixtures were therefore enriched with

[15]See THE JOURNAL, December, 1920, p. 521.

[16]See Report of the Bakerian Lecture delivered by Harold B. Dixon, published in the *Philosophical Transactions of the Royal Society of London* for 1893.

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oxygen. Fig. 10 is a typical photograph of a detonation finally obtained in a mixture containing 20 per cent of acetylene, 29.6 per cent of oxygen, and 50.4 per cent of nitrogen. It may be seen that the flame progresses with an accelerated velocity to a point about 7 in. from ignition at which it attains a very high and apparently uniform rate of travel. This is undoubtedly detonation though no attempt was made to determine the actual detonation velocity.

Fig. 11 which is reproduced from a photograph of a mixture of 20 per cent of acetylene, 32 per cent of oxygen and 48 per cent of nitrogen, shows detonation occurring just before the flame reached the top of the bomb. It is interesting to note that a slight change in the composition of the gas mixture exerts a great influence on the

FIG. 10—TYPICAL PHOTOGRAPH OF A DETONATION OBTAINED IN A MIXTURE CONSISTING OF 20.0 PER CENT OF ACETYLENE, 29.6 PER CENT OF OXYGEN AND 50.4 PER CENT OF NITROGEN HAVING AN INITIAL TEMPERATURE OF 25 DEG. CENT. (77 DEG. FAHR.) AND A PRESSURE OF 1 ATMOSPHERE

tendency to detonate or on the distance traveled by the flame before detonation was set up.

In studying the effect of the composition of mixtures of acetylene, oxygen and nitrogen on their tendency to detonate, four series of mixtures containing respectively 10, 12, 15 and 20 per cent of acetylene were selected. Amounts of oxygen ranging from less than the amount required to burn the acetylene to carbon monoxide to an excess of the amount required for combustion to carbon dioxide were used in each series. Photographs of the explosions of these various mixtures showed that detonation had been set up in only one case, that of the mixture containing 20 per cent of acetylene and oxygen in the combining proportion to give carbon monoxide. However, it must be pointed out that although detonation was obtained in only one instance, autoignition in the unburned gases ahead of the flame-front was exhibited over a wide range of mixtures. Fig. 12 is a typical example of this phenomenon as shown by a mixture containing 15 per cent of acetylene, 41 per cent of oxygen and 44 per cent of nitrogen.

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FIG. 11—PHOTOGRAPH OF A MIXTURE OF 20 PER CENT OF ACETYLENE, 32 PER CENT OF OXYGEN AND 48 PER CENT OF NITROGEN SHOWING THE OCCURRENCE OF DETONATION JUST BEFORE THE FLAME REACHED THE TOP OF THE BOMB
The Mixture in This Case Had an Initial Temperature of 25 Deg. Cent. (77 Deg. Fahr.) and Was Subjected to a Pressure of 1 Atmosphere

These results have indicated, to our mind, certain rather obvious conclusions, namely

(1) Detonation is most easily initiated in a mixture containing acetylene and oxygen in the combining proportion to give carbon monoxide

(2) The initiation of the detonating wave is delayed by the presence of an inert gas such as nitrogen. Mixtures containing acetylene and oxygen in the proportion given under (1) and more than approximately 50 per cent of nitrogen will not detonate in a 12-in. space at atmospheric pressure and temperature when ignited with a spark of normal intensity

(3) Oxygen in excess of the proportion given under (1) acts as inert gas and retards the initiation of detonation

Although these statements apply directly only to the behavior of acetylene mixtures, the work of other investigators on numerous gases has shown that the presence of inert gases in combustible mixtures inhibits detonation to a marked extent.

The effect of temperature on the tendency of acetylene mixtures to detonate was investigated by firing a series first at atmospheric pressure and temperature, and then at an initial temperature of 125 deg. cent. (257 deg.

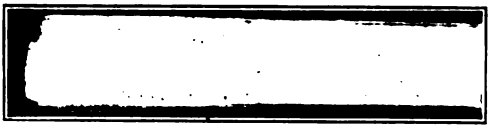

FIG. 12—PHOTOGRAPH SHOWING AUTOIGNITION IN A MIXTURE CONTAINING 15 PER CENT OF ACETYLENE, 41 PER CENT OF OXYGEN AND 44 PER CENT OF NITROGEN HAVING AN INITIAL TEMPERATURE OF 25 DEG. CENT. (77 DEG. FAHR.) AND A PRESSURE OF 1 ATMOSPHERE

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FIG. 13—RESULTS OBTAINED WITH A MIXTURE CONSISTING OF 20 PER CENT OF ACETYLENE, 30 PER CENT OF OXYGEN AND 50 PER CENT OF NITROGEN

In the View at the Left the Initial Temperature Was 25 Deg. Cent. (77 Deg. Fahr.) and the Pressure Was 15 Lb. Absolute. In the Other View the Initial Temperature Was Raised to 125 Deg. Cent. (257 Deg. Fahr.) and the Pressure to 25 Lb. Absolute, with the Result That Detonation Was Delayed

FIG. 14—RESULTS OBTAINED WITH A MIXTURE CONSISTING OF 22.50 PER CENT OF ACETYLENE, 33.75 PER CENT OF OXYGEN AND 43.75 PER CENT OF NITROGEN

In the View at the Left the Initial Temperature Was 25 Deg. Cent. (77 Deg. Fahr.) and the Pressure 15 Lb. Absolute. In the Other View the Initial Temperature Was 125 Deg. Cent. (257 Deg. Fahr.) and the Pressure Was 25 Lb. Absolute

fahr.) and 10-lb. gage pressure. Figs. 13 to 17, inclusive, present the comparative records obtained with four mixtures fired under these conditions. It is evident that in every case in which the initial temperature of the mixture was raised, the detonation occurs later. It is impossible to state definitely from so few results that an increased initial temperature actually delays the setting up of detonation in a given mixture. However, it is our belief that high initial temperature does not accelerate the initiation of the detonating wave as has recently been suggested.

AUTOIGNITION

It is well known that fuel-air mixtures ignite and burn when subjected to compression sufficient to raise the temperature of the mixture to or above its ignition point. As pointed out above, the movement of the flame from ignition compresses the unburned gases ahead of the flame-front. This increase in the density of the unburned gases is, of course, accompanied by an increase in the temperature and it is reasonable to assume that these gases could thus be ignited. The behavior of gas mixtures under high compression and the resulting flame movements are therefore of importance.

Dixon has presented the most interesting results on the behavior of gas mixtures at high pressures in an in-

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vestigation carried out primarily for the purpose of determining the ignition points of gaseous mixtures. Our particular interest is centered on the nature of the movement of the flame in gases ignited under the high temperature and pressure employed. In these experiments the various gas mixtures were compressed by driving a piston into a tube by means of a falling pendulum, thus obtaining extreme conditions of temperature and pressure almost instantaneously. With a mixture of carbon bisulphide and oxygen in the proportion of 1 to 5 the mixture ignited through autoignition. Relatively low velocities of flame movement were obtained even under the highest compressions, and there was no evidence of detonation. An idea of the severity of the tests to which Dixon[17] subjected these explosive mixtures, and the nature of the flame movement, is given in Table 4.

[17]See *Journal of the Chemical Society* (England), vol. 99, p. 588 and vol. 105, p. 2027.

FIG. 15—RESULTS OBTAINED WITH A MIXTURE OF 25 PER CENT OF ACETYLENE, 37.5 PER CENT OF OXYGEN AND 37.5 PER CENT OF NITROGEN
In the View at the Left the Initial Temperature Was 25 Deg. Cent. (77 Deg. Fahr.) and the Pressure 15 Lb. Absolute. In the Other View the Initial Temperature Was 125 Deg. Cent. (257 Deg. Fahr.) and the Pressure Was 25 Lb. Absolute

FIG. 16—RESULTS OBTAINED WITH A MIXTURE OF 27.50 PER CENT OF ACETYLENE, 41.25 PER CENT OF OXYGEN AND 31.25 PER CENT OF NITROGEN
In the View at the Left the Initial Temperature Was 25 Deg. Cent. (77 Deg. Fahr.) and the Pressure 15 Lb. Absolute. In the Other View the Initial Temperature Was 125 Deg. Cent. (257 Deg. Fahr.) and the Pressure Was 25 Lb. Absolute

FIG. 17—RESULTS OBTAINED WITH A MIXTURE OF 30 PER CENT OF ACETYLENE, 45 PER CENT OF OXYGEN AND 25 PER CENT OF NITROGEN
In the View at the Left the Initial Temperature Was 25 Deg. Cent. (77 Deg. Fahr.) and the Pressure 15 Lb. Absolute. In the Other View the Initial Temperature Was 125 Deg. Cent. (257 Deg. Fahr.) and the Pressure Was 25 Lb. Absolute

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TABLE 4—BEHAVIOR OF MIXTURES OF CARBON BISULPHIDE AND OXYGEN IN THE PROPORTION OF 1 TO 5 AT HIGH COMPRESSION IN A TUBE 12 MM. (0.048 IN.) IN DIAMETER AND 650 MM. (25.59 IN.) LONG

Compression-Ratio	Calculated Pressure, atmospheres	Calculated Temperature		Nature of Flame Movement
		Deg. Cent.	Deg. Fahr.	
1 to 7.3	15.30	335	635	Autoignition near end of tube, no detonation.
1 to 9.4	21.55	394	723	Autoignition near end of tube, no detonation.
1 to 10.5	25.06	422	792	Autoignition near end of tube, no detonation.
1 to 10.5[18]	25.06	422	792	Velocity of 14 meters per sec. (45.93 ft. per sec.)
1 to 10.5[19]	25.06	422	792	Velocity of 60 meters per sec. (196.85 ft. per sec.)

[18]Slow compression.
[19]Fast compression.

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Commenting on the results with carbon bisulphide, Dixon says

> The flame took an appreciable time to spread through the space occupied by the gas, and in no instance did the flame travel through the tube with a velocity approaching that of detonation. In the fastest instance observed, the flame traveled 25 mm. (0.984 in.) in 0.00025 sec., that is, at 100 meters per sec. (328.08 ft. per sec.), whereas the explosion wave (detonation) travels in this mixture at a rate of nearly 1800 meters per sec. (1.12 miles per sec.).

Further results from the same work of Dixon on mixtures of hydrogen and oxygen, indicated that autoignition took place and that detonation may have developed later in some cases. Results obtained with a mixture of hydrogen and oxygen in the proportion of 1 to 3 are given in Table 5.

In commenting on results obtained with hydrogen-oxygen mixtures in the proportion of 2 to 1 a mixture having a very high detonation velocity of 2800 meters per sec. (1.74 miles per sec.), Dixon says

> When electrolytic gas was fired by compression the spread of the flame was far more rapid than that with excess oxygen; but in no case was the gas detonated instantaneously, even when the fall of the pendulum was unchecked except by the explosion itself.

In these experiments the flame was moving through a gas which was not only at a high density but also at a high temperature, in the one case, approximately 975 deg. cent. (1787 deg. fahr.). In spite of these very high temperatures, the dilute mixtures of carbon bisulphide and oxygen and of hydrogen and oxygen showed low rates of flame movement as compared with what one would expect under these conditions.

It would be expected that when a gas is compressed to a temperature far above its ignition point, every particle of the inflammable gas would essentially either be oxidized or decomposed instantaneously. Dixon has shown, however, that this is not necessarily the case, but that the ignition starts at a point and proceeds slowly with a gradual acceleration, the actual velocity attained depending to a large extent on the point at which ignition started. For example, in his experiments the maximum velocities attained appear to be comparatively low when the autoignition started near the center of the tube,

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TABLE 5—BEHAVIOR OF A MIXTURE OF HYDROGEN AND OXYGEN IN THE PROPORTION OF 1 TO 3 AT HIGH COMPRESSION

Compression-Ratio	Length of Column of Gas at Moment of Firing		Calculated Pressure, atmospheres	Calculated Temperature		Behavior of Gas
	Cm.	In.		Deg. Cent.	Deg. Fahr.	
1 to 15.0	3.6	1.42	44.3	550 to 578	1022 to 1072	Autoignition near middle of tube. Detonation may have developed.
1 to 18.0	3.0	1.18	57.2	640	1184	Autoignition near end of tube. Burned slowly.
1 to 27.0	2.0	0.79	100.9	810	1490	Autoignition near end of tube. Burned slowly.
1 to 41.5	1.3	0.51	184.5	975	1787	Autoignition near end of tube. Detonation may have developed

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FIG. 18—A TYPICAL EXAMPLE OF FLAME MOVEMENT IN A MIXTURE CONSISTING OF APPROXIMATELY 8 PER CENT OF SULPHURIC ETHER AND 92 PER CENT OF AIR HAVING AN INITIAL TEMPERATURE OF 160 DEG. CENT. (320 DEG. FAHR.) AND A PRESSURE OF 65 LB. ABSOLUTE

whereas relatively high velocities were attained when the autoignition started near one end of the tube and had the full length of the tube to travel.

The above results from Dixon's early work are, of course, on gases whose behavior may not be representative of that of the fuels used in internal-combustion engines. In Dixon's abstract of results recently presented in England which appeared in THE JOURNAL[20], he discloses that he has been studying the behavior under compression of such fuels as pentane, hexane, benzine, alcohol and ether. The details of these results are awaited with keen interest.

As stated above, in our work on the influence of increased temperature and pressure on the nature of flame propagation a study was made of a badly knocking fuel, namely ether. Mixtures containing approximately from 6 to 8 per cent of ether were ignited at 150 to 160 deg. cent. (302 to 320 deg. fahr.) initial temperature and pressures of from 65 to 75 lb. absolute. Fig. 18 is a typical example of the characteristic flame-record obtained. It may be seen that the flame progressed from ignition at a slowly accelerated rate, until it was arrested a short distance beyond the center of the cylinder. At the time of the arrest autoignition appeared in the unburned gas at a point about equidistant between the advancing flame-front and the top of the bomb. Flame spread from this center of autoignition toward both the top of the bomb and the original flame-front, causing in the latter case a decided recession of the original flame-front. In some cases, after total inflammation had been accomplished, vibrating compression waves were set up in the burned gases similar to those described earlier in this paper.

The most important part of our work with ether-air mixtures was the recording of the pressure development during explosions in which the phenomenon of autoigni-

[20] See THE JOURNAL, December, 1920, p. 521.

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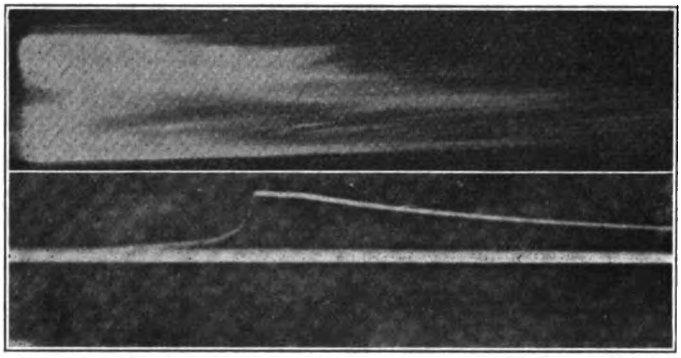

FIG. 19—THE FLAME (UPPER) AND THE PRESSURE (LOWER) RECORD OF AN EXPLOSION OF AN ETHER-AIR MIXTURE AT A TEMPERATURE OF 150 DEG. CENT. (302 DEG. FAHR.) AND A PRESSURE OF 65 LB. ABSOLUTE

tion took place. Fig. 19 gives the flame and pressure records of an explosion of an ether-air mixture at 150 deg. cent. (302 deg. fahr.) and 65 lb. absolute pressure. In this explosion autoignition appeared but no vibrations occurred in the after-burning. It may be noted that the development of pressure was slow until auto-

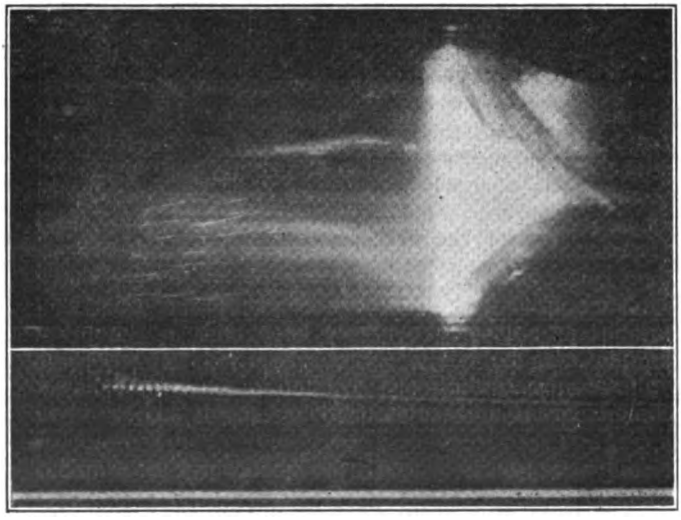

FIG. 20—THE FLAME (UPPER) AND THE PRESSURE (LOWER) RECORD OF AN EXPLOSION OF AN ETHER-AIR MIXTURE AT A TEMPERATURE OF 150 DEG. CENT. (302 DEG. FAHR.) AND A PRESSURE OF 75 LB. ABSOLUTE

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ignition appeared. Then the pressure increased with great rapidity.

Fig. 20 gives the records of an ether-air mixture at 150 deg. cent. (302 deg. fahr.) and 75 lb. absolute pressure. Here again autoignition of the high-density gas ahead of the flame-front was evident and in this case distinct vibrations were recorded. The records of this explosion are more clearly shown in Fig. 21, in which the flame and pressure curves have been plotted to the

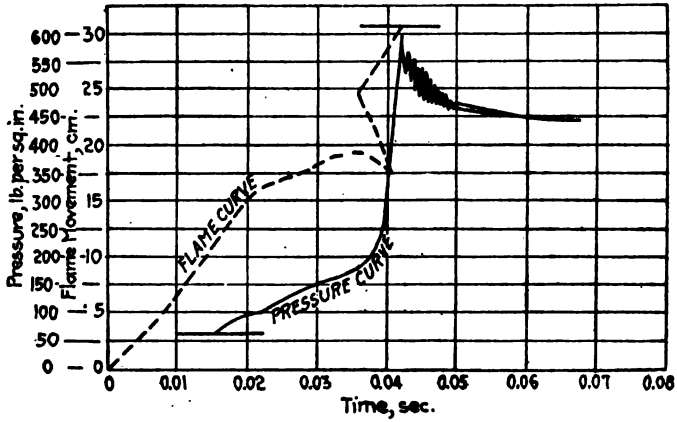

FIG. 21—FLAME AND PRESSURE RECORD OF THE ETHER-AIR MIXTURE AT A TEMPERATURE OF 150 DEG. CENT. (302 DEG. FAHR.) AND AN ABSOLUTE PRESSURE OF 75 LB.

same time-scale. From this it can be seen that the first appearance of pressure occurred after the flame had traveled approximately one-third of the distance to the top of the cylinder, and that the pressure was thereafter developed slowly until the time at which autoignition occurred. In fact the flame had traveled nearly two-thirds the length of the bomb and a pressure of only 115 lb. per sq. in. had been developed in 0.036 sec. With the appearance of autoignition in the high-density gas pressure developed very rapidly, 425 lb. per sq. in. being recorded in 0.006 sec. The instant of maximum pressure was found to coincide with the instant of total inflammation of the bomb. Upon the attainment of maximum pressure rapid vibrations of the Midgley pressure indicator were recorded. The period of these vibrations has been carefully determined and found to agree exactly with that of the vibrating compression-waves in the after-burning as recorded in the flame photograph. In our opinion the pressure record obtained in this explosion appears sim-

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ilar to that shown by the Midgley indicator while ether is knocking in an engine.

The Nature of the Fuel Knock

Of the many theories which have been presented on the nature of the "fuel knock," that of the detonation of the fuel-air mixture in the engine cylinder has recently received considerable credence, and it is certain that if detonation can be set up in the combustion-chamber of an engine the phenomenon of knocking would be satisfactorily explained. However, it has been our experience to date that detonation is set up only with great difficulty in a closed cylinder of small dimensions.

On the other hand, autoignition of the high-density gases ahead of the flame-front occurs over a wide range of fuel mixtures and conditions and gives a sudden development of pressure similar, in our opinion, to that characteristic of a knocking explosion. It is possible that this autoignition may set up detonation in some cases, thereby acting as an intermediate stage in knocking. Our experiments have not been carried to a definite conclusion, and present data do not warrant presentation of autoignition as a positive explanation for knocking. It is our feeling, however, that information at hand favors more strongly the theory of autoignition of the high-density gases ahead of the flame-front than that of detonation.

The following four characteristics of the fuel knock have been generally recognized: (*a*) high initial temperature and (*b*) high initial pressure favor knocking; (*c*) the tendency to knock increases with decrease in volatility in comparing the members of the same homologous series and (*d*) volatility and knocking have no relation when different homologous series are compared.

Autoignition of the gas ahead of the flame-front is likewise favored by a high initial temperature or pressure of the gas charge. The only results available on the effect of increased temperature on the tendency to detonate, indicate that high temperature inhibits detonation. Moore [21] shows that in the same homologous series the autoignition point becomes lower as the boiling point rises. With decrease in volatility of the members of a series their tendency to autoignite and knock are increased. There are no data at hand to show the relation of the tendency to detonate with the volatility of a given series of compounds.

[21] See *Journal of the Society of Chemical Industry*, vol. 36, p. 109.

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The many determinations of autoignition points reported in the literature on the subject show conclusively that no relation exists between the volatility and the autoignition point when the comparison is extended to various series of compounds. The information on the tendency of liquid fuels to detonate is meagre. As stated above, Dixon classes ether and alcohol together in their tendency to detonate, and states that pentane and benzine do not accelerate to detonation at atmospheric temperature and pressure. Our attempts to obtain detonation with ether at high temperature and pressure in a 12-in. cylinder were failures. These results are not consistent with the order of the fuels to knock[22]; the tendency being, respectively, ether, pentane, benzine and alcohol.

It should be emphasized also that there is a certain necessary distance of flame travel from ignition to the point at which detonation is set up, and that the distance is increased by the presence of diluent gases, even excess oxygen. In the engine the explosion chamber is of very small dimensions and the atmosphere is air diluted with from 10 to 25 per cent of the products of combustion. The possibility of detonation under such conditions appears exceedingly remote.

SUMMARY

(1) Apparatus and methods of study have been developed with which the rate and nature of the flame movement and pressure development in gaseous explosions can be recorded under conditions approximating those of the internal-combustion engine

(2) It has been shown that in the case of acetylene-air mixtures ignited at atmospheric temperature and pressure the maximum velocity of flame movement is obtained with that mixture corresponding closely to the theoretical proportion for the formation of carbon monoxide

(3) It has been substantiated that first record of pressure development occurs after an appreciable distance of flame travel, and that the instant of maximum pressure development coincides with that of total inflammation of the gas charge

(4) A theory has been presented that the arrest occurring in mixtures fired without turbulence, and the consequent vibrations noted in the burning gases, are due essentially to the high density developed in the gases ahead of the flame-front

[22] See TRANSACTIONS, vol. 15, part 2, p. 685.

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(5) It has been confirmed that turbulence greatly accelerates flame propagation, and it has been shown that turbulence changes the character of the flame travel by the elimination of the sudden arrest and vibratory movement

(6) Within the limits of the experiments carried out it was found that increased temperature and pressure have little effect upon the rate of flame propagation

(7) The initiation of a detonation has been found possible at atmospheric conditions and in a closed cylinder of 12-in. length only by the use of relatively high concentrations of acetylene and a thorough enrichment of the atmosphere with oxygen

(8) Preliminary results have been presented which indicate that high temperature inhibits the initiation of the detonation

(9) It has been shown that autoignition of the high-density gases ahead of the flame-front occurs over a wide range of mixtures and conditions and that it is especially favored by high temperature and pressure.

(10) A record of pressure development in an explosion of an ether-air mixture in which autoignition occurred in the high-density gases ahead of the flame has been obtained; this record, in our opinion, is similar to that of a knocking explosion of ether

(11) A theory has been advanced that autoignition of the high-density gases ahead of the flame-front is accountable for the fuel knock

THE DISCUSSION

DR. H. B. DIXON:—The paper is naturally of great interest to me, for I have been working on the theory of the explosion of gases for more than 40 years, and during the last 3 years have been experimenting on the combustion of the vapors of pentane, hexane, benzene, alcohol and ether with the object of obtaining data that might be useful to the designers of internal-combustion engines.

About 20 years ago I took photographs on a moving film of explosions in strong glass cylinders 9 in. long by 2½ in. internal diameter, fitted at one end with a delicate pressure indicator, and so obtained records of the

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spread of the flame and of the pressures registered after the passage of the spark, which itself was recorded both on the photographic film and on the pressure-card. The negatives, though fairly visible during development, made poor prints, and the pressure curves, owing to the inertia of the piston used, were comparable only for explosions that traveled at about the same rate. The photographs showed the increase in luminosity and velocity as the flame traveled from the ignition-point; they also showed the marked effect on the flames of the position of the spark, whether at the end of the cylinder, i.e., flush with the end-wall, or at a short distance from it. The indicator showed that the piston began to move when a pressure-wave starting from the beginning of the explosion was calculated to reach the piston after traveling with the velocity of sound through the unburnt gases ahead of the flame. I did not publish these results, but proceeded to attack each part of the problem separately. After my experience I can congratulate the American experimenters on the skill with which they have combined the photographic records of the movements of the flame and the variations of pressure in the explosion vessel.

In discussing the results arrived at by the authors, I may say that I am in cordial agreement with their main observations and conclusions that

(1) When acetylene-air mixtures are fired by a spark at one end of a closed cylinder, the average velocity of the flame is greatest when the acetylene forms between 8 and 10 per cent of the mixture, and when acetylene-oxygen-nitrogen mixtures are fired an explosion-wave or detonation is set up most readily when the oxygen is just sufficient to burn the carbon to monoxide and the hydrogen to steam, an excess of oxygen acting as inert gas

(2) When fired in closed vessels the flame travels with increasing velocity from the spark, but is usually checked before it reaches the end of a short tube or cylinder

(3) If the flame travels toward the end of a tube drawn out into a hollow cone the pressure may be piled up, as in the case of a tidal bore in a narrowing estuary, until even mixtures of relatively high ignition-point can be fired ahead of the advancing flame by the heat of compression. It has been shown in the *Proceedings of the Royal Society of London* that hydrogen and oxygen can be fired in this way

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(4) It is not easy to set up an explosion-wave or detonation in a short cylinder, although acetylene and ethylene will detonate with air when fired in a long tube; and I do not believe that the "knocking" or "pinking" heard in gas engines is due to a true explosion-wave. In the explosion-wave the flame is traveling through unburnt gas at a constant velocity that is twice that of sound in the burning gases. Behind the wave-front the gas is moving forward en masse with the velocity of sound, and the wave-front is traveling forward with the velocity of sound in this moving medium. This statement admits of an easy confirmation, for if a sound-wave or compression-wave is made to travel through the burning gases immediately behind the wave-front and in the same direction while the explosion is photographed on a moving film the sound-wave traces a line which is practically parallel with the line of the explosion-wave, i. e., it is traveling forward through the burning gases with the same velocity as the explosion-wave. In a photograph published in the *Philosophical Transactions of the Royal Society of London*[23] the sound-wave was started too far behind the wave-front to move forward with the same velocity as the medium in which it was moving had begun to slow down; later photographs have shown that the nearer the sound-wave is to the wave-front the more nearly does it equal it in speed

In agreement with their first conclusion I have found[24] that when the explosion-wave is propagated through acetylene-oxygen mixtures there is an increase in the rate of the explosion when the oxygen is reduced from 2½ to 1½ times the volume of the acetylene, and similarly in the case of ethylene-oxygen mixtures. Moreover, the replacement of the "extra" volume of oxygen by an equal volume of inert nitrogen has a less retarding effect on the rate, as is brought out in Table 6.

It is an inference from these, and from similar results obtained with other carbon compounds, including pentane, benzene and alcohol, that the original burning of the carbon resulted in the formation of carbon monoxide; probably in some cases with the momentary existence of an intermediate body which breaks up as shown in the reactions below

$$C H_4 + O_2 = H_2 C O + H_2 O$$
$$H_2 C O = H_2 + C O$$

[23] See the *Philosophical Transactions of the Royal Society of London*, vol. 200A, plate 12, fig. 23.
[24] See the *Philosophical Transactions of the Royal Society of London*, vol. 184, p. 120.

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TABLE 6—RATE OF PROPAGATION OF EXPLOSION-WAVE

Mixtures	Rate of Propagation, meters per sec.	miles per sec.
Acetylene Mixtures		
$2\ C_2H_2 + 3\ O_2$	2,716	1.687
$2\ C_2H_2 + 3\ O_2 + 2\ N_2$	2,414	1.500
$2\ C_2H_2 + 5\ O_2$	2,391	1.486
Ethylene Mixtures		
$C_2H_4 + 2\ O_2$	2,581	1.604
$C_2H_4 + 2\ O_2 + 2\ N_2$	2,413	1.499
$C_2H_4 + 3\ O_2$	2,368	1.471

The carbon monoxide formed, directly or indirectly, would then react, in the absence of free oxygen, with the steam, and an equilibrium would be reached as the gases cooled

$$C\,O + H_2\,O \leftrightarrow C\,O_2 + H_2$$

In the case of cyanogen the evidence is more direct. When the explosion-wave is propagated through the mixture in equal volumes the carbon is found, almost entirely, as carbon monoxide, and the rate of propagation and the violence of the explosion are both much greater than in the mixture with two volumes of oxygen when the carbon is found in the residual gases as carbon dioxide.

Again when a volume of nitrogen is added to the mixture in equal volumes, $O_2N_2 + O_2$, it has a less retarding effect than an equal volume of oxygen, as would be the case if both were inert in the primary combustion. Later experiments with nitrogen and argon as diluents have shown me that when the cyanogen-oxygen mixture is damped down by an inert gas the rate of the explosion-wave is not independent of the diameter of the tube, and the wave travels faster in a straight pipe of 19-mm. (0.748-in.) bore than in one of only 9 mm. (0.354 in.); but this does not affect the comparative damping effect of the nitrogen and oxygen added.

One obvious explanation presents itself, and I think it is the correct one, that carbon dioxide, if directly formed in the explosion-wave of cyanogen with two volumes of oxygen, would be dissociated at the high temperature produced. If this is the explanation it follows that the carbon dioxide found in the analysis of the residual gases from the exploded mixture, and practically all the carbon is found as the dioxide, must have been formed behind the wave-front, or while the gases were cooling.

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There would be consequently a longer column of reacting gases behind the wave-front since the cooling would be retarded by the gradual burning of the carbon monoxide to dioxide. That there is such a longer column I have verified by two methods, that of the "jet" and that of the "window."

In the first photographs were taken of the jets of flame thrown out from a long tube in which the two mixtures were detonated, the tube being opened just before firing. When the cyanogen was fired with two volumes of oxygen the jet photographed was much longer and more luminous than when fired with one volume of oxygen. The jet is thrown out only after the flame-front has traversed the whole column of combustible gases. In the latter method photographs were taken on a rapidly moving film of the illumination of a small window in a tube as the explosion-wave passed. When the cyanogen was detonated with one volume of oxygen the illumination was much brighter but much shorter in duration than when fired with two volumes of oxygen.

The slight lowering of the velocity of the flame of acetylene-air mixtures found by the authors, when the initial temperature was raised at constant pressure from 25 to 125 deg. cent. (77 to 257 deg. fahr.), was what I should have expected from my experiments. It was shown, for example, that the ignition-point of electrolytic gas[25] when fired by compression is the same, 526 deg. cent. (978.8 deg. fahr.) whether the gases were originally at room temperature or at 100 deg. cent. (212 deg. fahr.), although of course less compression was required to fire the gas at the higher temperature. Again the explosion-wave[26] is propagated through gas mixtures at slightly lower velocities when the gases are initially heated at constant pressure to 100 deg. cent. (212 deg. fahr.), as shown in Table 7.

With regard to initial changes of pressure, Dr. Coward and I found that when hydrogen and oxygen are heated separately and then brought together, the ignition temperature is only slightly raised from about 590 deg. cent. (1094 deg. fahr.) at atmospheric pressure to 600 deg. cent. (1112 deg. fahr.) by halving the pressure; while by doubling the pressure it is lowered more appreciably to about 560 deg. cent. (1040 deg. fahr.).

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[25] See *Journal of the Chemical Society* (England), vol. 105, p. 2046.

[26] See the *Philosophical Transactions of the Royal Society of London*, vol. 184A, p. 108.

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TABLE 7—RATE OF PROPAGATION OF EXPLOSION-WAVE

Mixture	$2\,H_2 + O_2$	$C_2H_4 + 2\,O_2$	$C_2N_2 + O_2$
Rate at 10 Deg. Cent., meters per sec.	2,821	2,581	2,728
Rate at 50 Deg. Fahr., miles per sec.	1.758	1.609	1.695
Rate at 100 Deg. Cent., meters per sec.	2,790	2,538	2,711
Rate at 212 Deg. Fahr., miles per sec.	1.734	1.577	1.746

Experiments on the velocity of the explosion-wave show that it is propagated at a slightly increased rate with increased initial pressure, as is brought out in Table 8, but a maximum rate seems to be reached soon.

The reason an increase of 100 deg. cent. (212 deg. fahr.) in the initial temperature of the gases at constant pressure has but a small effect on the propagation of the flame is probably that the temperature of the reacting gases is but little altered.

If a gas mixture has an ignition-point of 600 deg. cent. (1112 deg. fahr.) it means that at this temperature the gases begin to heat up automatically by a flameless combustion, which increases in rate until at some high temperature, probably well over 1000 deg. cent. (1832 deg. fahr.), the flame appears[27]. With many gas mixtures the rate of combination a few degrees below the ignition-point is negligible; chemical action is slow in the pre-flame period of combustion, and only becomes rapid with the appearance of the flame itself. If the initial temperature of the gas is raised 100 deg. cent. (212 deg. fahr.) this rise is not added to the flame-temperature, but only, by giving the system a "push-off," allows the flame-temperature to be reached a little earlier. However, when

[27] See *Journal of the Chemical Society* (England), vol. 106, p. 2033.

TABLE 8—RATE OF PROPAGATION OF EXPLOSION-WAVE AT DIFFERENT PRESSURES

Mixtures	$2\,H_2 + O_2$	$C_2H_4 + 2\,O_2$
500 mm., meters per sec.	2,775	2,280
19.685 in., miles per sec.	1.724	1.417
760 mm., meters per sec.	2,821	2,322
29.921 in., miles per sec.	1.758	1.443
1000 mm., meters per sec.	2,850	2,319
39.370 in., miles per sec.	1.771	1.497
1500 mm., meters per sec.	2,872	....
59.055 in., miles per sec.	1.786	....

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the temperature of the burning gases is increased, by the passage of an intense pressure-wave through the flame, the effect on the combustion may be strongly marked, and when gases are fired by adiabatic compression the spread of the flame is as a rule more rapid, and the explosion-wave, if it can exist, is more rapidly set up than under normal temperature and pressure conditions.

Many of my photographs show, by delicate striæ, the forward movement of the gas behind the wave-front, the gradual arrest and the backward movement which takes place independently of any reflected or other pressure waves. The striations, however, become much more marked when pressure-waves are reflected backward and forward through the burning gases.

Origin of the Pressure-Waves Crossing the Burning Gases

There are several sources of pressure-waves that may be propagated through the burning gases in an explosion

(1) The explosion-wave, set up after a certain distance of travel in a long tube, may strike the end of the tube and be reflected backward. Its rate and intensity depend on the nature of the burning gases. For instance, when cyanogen is exploded with its own volume of oxygen the chemical reaction is very rapidly completed.

$$C_2N_2 + O_2 = 2\,CO + N_2$$

The reflected wave has therefore to travel the greater part of its journey through gases in which the chemical action is little or nil. But when cyanogen is fired with twice its volume of oxygen the flame lasts much longer owing to the carbon monoxide, produced in the primary reaction, forming carbon dioxide as the gases cool.

$$C_2N_2 + 2\,O_2 = 2\,CO + O_2 + N_2$$

$$2\,CO + O_2 + N_2 = 2\,CO_2 + N_2$$

The reflected waves in this mixture are more strongly marked

(2) At the point where the explosion-wave is set up there is propagated backward a pressure-wave which I termed the retonation-wave. This resembles in many respects the reflected wave from the explosion-wave. It is easy to choose a mixture of gases of such a kind and a tube of such a length that the explosion-wave or detonation is set up just at the moment when the flame reaches the end

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of the tube. There is no unburnt gas to carry forward the explosion-wave, but the retonation-wave is sent backward and the reflected-wave is superposed on it, so that the pressure-wave moving backward through the only partially burnt gas is almost identical at first with the explosion-wave in velocity and violence[28]

(3) A pressure-wave, traveling with the velocity of sound in the unburnt gas, is propagated from the point where the explosion is initiated by the spark or by a small detonator. This pressure-wave traveling at constant velocity will be overtaken by the flame with its accelerated motion, if there is sufficient length of run; but if the tube is short the pressure-wave reaches the end of the tube first, and is reflected backward so as to meet the advancing flame, which, as I read the photographs, is retarded and even thrown back in some cases for a space, while the pressure-wave is being propagated backward through the burning gases, its course being now faster and marked by increased light

If the tube is of such a length that this initial pressure-wave and the flame reach the end of the tube at the same instant, the reflected waves of both are superposed, and the combined wave is comparable with a retonation-wave. This, I think, is the commonest cause of "knocking" in an explosion cylinder.

A retonation-wave might be set up at the same instant that the flame and the initial pressure-wave reached the end of the tube together. If this were to happen the combined return-wave would hardly be distinguishable from a detonation. The American experimenters differ from me as to the cause of the arrest of the flame before it reaches the end of the cylinder, and as to the source of the pressure-wave proceeding from that point. We are agreed that something runs up against the flame, or the flame runs into something that checks it suddenly. I attribute this to a pressure-wave, started by the initiation of the explosion at the spark, and continually "backed up" by the moving flame gathering speed behind it. The front of this column of high pressure, with the gas moving bodily in its wake, is reflected from the end of the tube. Whatever it is, it is traveling with the velocity of sound in the unburnt gas; I have found this to be true with gases varying in vapor density from that of electrolytic gas, 6, to that of cyanogen with an equal volume

[28] See the *Philosophical Transactions of the Royal Society of London*, vol. 200A, plate 15, figs. 44 to 51.

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of oxygen, 21. The authors attribute the arrest of the flame to the equalization of pressure in front of and behind the flame: "When the pressure is equal the flame-front is no longer pushed forward; the propagation is arrested." They observe that the equalization of pressure should be a gradual process and they would expect the arrest of the flame to be gradual rather than sudden, as it is. But if the advance of the flame is not checked by a pressure-wave accompanied by a backward movement of the gas, I cannot understand why the flame should not proceed through the high-pressure area with undiminished velocity, since high pressure, unaccompanied by movement, has little influence on the rate of propagation. The backward movement of the gas is made visible by the striæ in the flame as the pressure-wave passes backward through the burning gas, but this backward movement and the pressure-wave itself are caused, according to the authors, by the arrested flame itself.

Let me refer to a photograph that my colleague, Dr. Campbell, has recently taken and is reproduced in the lower left corner of Fig. 22. An explosion-wave has been propagated through a mixture of cyanogen, oxygen and nitrogen in a narrow tube opening into a wide one. The flame is traveling from right to left while the film is moving vertically downward. The explosion-wave is damped down soon after the flame emerges into the wider vessel, at the point marked by the white arrow, but it sends forward through the unburnt gases an intense pressure-wave which, leaving behind the slackening flame, reaches the end of the wide tube first and is reflected from it. On drawing the path of this pressure-wave from the calculated velocity of sound in the gases, it is found, within the limit of error, to strike the advancing flame at the point *A* where the flame is arrested. The flame is driven back and the striæ show that the gas itself is moving backward in the wake of the pressure-wave until the latter strikes the end-wall through which the narrow tube debouches. The wave penetrates the narrow tube, forming a line of light just visible at *B*, but the greater portion is reflected from the wall and is seen proceeding forward again from right to left until it reaches the flame-front at *C*, near the second black reference line. The flame-front is now pushed forward again, but the pressure-wave, suffering a slight reflection which is visible in the photograph, where it meets the flame-front, passes into the unburnt gas ahead of the flame, is again reflected and

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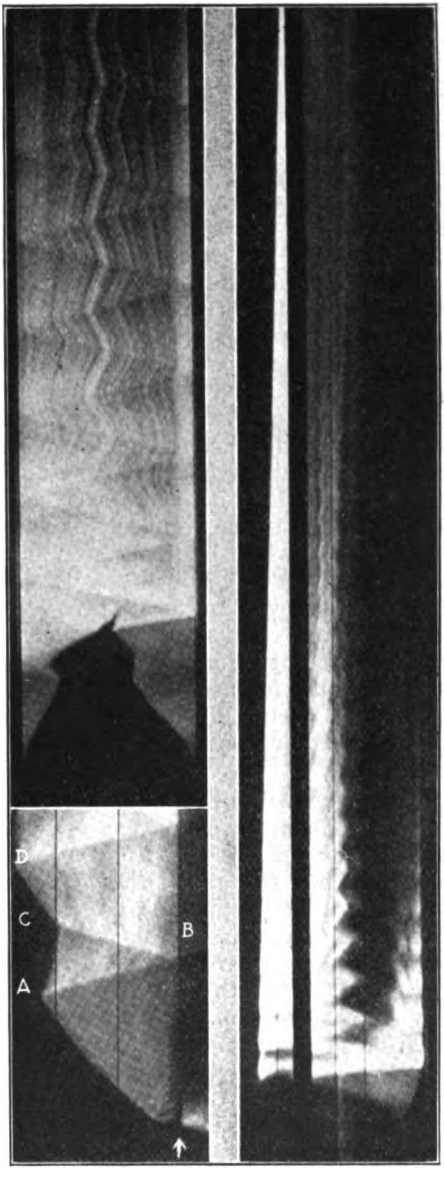

FIG. 22—PHOTOGRAPHS OF FLAME MOVEMENT IN DIFFERENT MIXTURES

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arrests the flame a second time at *D*, where it again passes backward through the flame, reproducing its previous action. The two points of arrest, *A* and *D*, correspond, within the limit of error, with the point where a pressure-wave traveling with the velocity of sound through the unburnt gas would meet the flame.

In the photograph shown in the upper left of Fig. 22 the explosion was started simultaneously at the two closed ends of the tube. The spark on the right being more intense caused the flame on that side to start faster than the flame on the left. An initial pressure-wave runs forward from each side, that from the right traveling farther before it meets the slower-moving flame on the left. We can see where it meets and throws back the left-hand flame, passes through it and is reflected from the closed end. On its return it checks the backward movement of the left-hand flame and hurries it forward again. Passing now ahead of the flame it is invisible until it strikes the right-hand flame which it throws back sharply, and is propagated through it to the right-hand end. The right-hand flame has meanwhile been arrested by the initial pressure-wave from the left, which passing through it is reflected from the end-wall and in its turn hurries up the right-hand flame and checks the left-hand flame. The initial flames, not being symmetrical, give rise to pressure-waves of unequal intensity. The upper part of this photograph gives a pretty illustration of the coalescence of two waves, or rather the absorption of the weaker by the stronger wave.

The photograph shown in Fig. 22 at the right gives the movements of the flame in a mixture of hydrogen with three volumes of oxygen fired by a spark near the right side of the tube while the gases were being compressed by the sudden thrust of a piston from the left. At the moment the spark was passed the gas had been compressed to nearly one-quarter of its original volume, from a column of 24 in. in length to 6 in. and of course was heated up by the compression. The pressure-wave started by the initiation of the explosion reached the advancing face of the piston before the flame, and on reflection checked the flame near the broad black shadow thrown by the clamp and traversed the burning gases to the right-hand end. The peculiarity of this hitherto unpublished photograph is that the gas was ignited by the pressure-wave at the face of the piston, or possibly in an interstice between the piston-head, which was wrapped

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with silk thread, and the glass tube. The flame so started by compression did not advance quickly, although it was very luminous owing to the burning of a little lanoline used as a lubricant on the thread. It was easily outdistanced by the pressure-wave reflected from the face of the steel piston. The photograph shows the comparatively slow advance of the piston which was finally arrested by a collar when it had penetrated 3 in. farther. The tail of luminosity coming from below in the center of the picture is due to the remains of the lanoline still burning when the film, which was 1 meter (39.37 in.) long, had made a complete revolution.

It will be seen from this account that I agree with the authors of the paper that there is a column of high pressure driven ahead of the burning gases in the first phase of the explosion, and that this pressure causes the arrest of the flame in a short vessel. I differ from them, it seems, in that I think that the front of this column of high pressure reaches the end of the tube and is reflected from it. When the reflected pressure-wave meets the advancing flame it checks it by its bodily motion, and itself proceeds through the burning gases with an increased speed. Perhaps we may find that our difference is mainly one of expression. Many experiments have shown that this pressure-wave travels with the velocity of sound, and I have called it, perhaps wrongly, a "sound-wave," for short.

Nearly all my photographs show the "stratification" in the flame becoming more and more marked as the pressure-waves cross and recross the tube. Sometimes the striæ appear to be driven to one side or other of the tube, leaving dark spaces. This stratification is no doubt due to solid particles, minute fragments of glass and metal, and to particles of carbon, when carbon compounds were fired, raised to incandescence and thrown backward and forward by the movements of the gas they float in. The regularity of the stratification suggests an arrangement like the dust figures in Kundt's tube when the length of the tube is not an exact multiple of the wave length.

On one other point I think my results are at variance with the authors' conclusions. They state that "The instant of maximum pressure development coincides with that of total inflammation of the gas charge." If the authors mean by "total inflammation" the fact that the flame has spread from end to end of the vessel and that

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the whole column of gas is visibly alight, it may happen that the pressure is greatest at that moment, but in many cases, and I believe in most instances, the greatest mean pressure occurs after the flame has completely filled the vessel. A detonation-wave, as I have shown, may be on the point of starting when the flame reaches the end of the tube. As a result a retonation-wave superposed on a reflection-wave starts back through the burning gases, and its rapidity bears witness to the high temperature and high pressure produced in it. A pressure-gage fixed at the end of the tube from which the retonation-wave starts back would of course indicate this high pressure, and it would coincide with the arrival of the flame, completing the "total inflammation." But the retonation-wave traversing the already burning gases would bring about increased chemical action, and raise the mean pressure of the whole column of gas after the "total inflammation." In many cases the pressure-waves crossing the vessel from end to end have the greatest rapidity, indicating the highest mean temperature and pressure, some time after the whole column of gas has been ignited.

The main difference between the initial phases of the explosion and the explosion-wave or detonation appears to lie in the rapidity of the chemical action. In the initial slow phase only a few of the collisions between molecules result in a chemical change; the flame therefore persists while the gradual burning proceeds and the luminosity is small. In the explosion-wave most of the collisions between suitable pairs of molecules result in a chemical change; the flame therefore is short-lived, except where dissociation occurs, and is intensely hot and luminous.

There is still much that requires elucidation in the explosion of gases, especially as to the temperatures reached. The mode in which turbulence acts is very important in regard to gas-engine practice. My colleagues and I are trying to get photographic evidence on this in the explosion of hydrocarbons, alcohol and ether. I may take this opportunity of correcting a statement I made last year, for we have now good records of the starting of explosions in mixtures of these vapors with oxygen and nitrogen, and find that alcohol is *not* the fastest off the mark, as we thought from our first faint photographs, but is rather a slow "starter" compared with its competitors.

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F. W. STEVENS:—One cannot get away from the conviction that there is after-burning; that the flame phenomena do not include all of the reaction. It seems to me that the species into which a fuel may break up necessarily have different velocity-constants, and that in the rout of an explosion they will naturally take different positions along the road, the worst wounded and slowest being the longest on the way. Yet, if we interpret correctly the sound-waves passing through these gases behind the flame, they must be homogeneous, for they show constant velocity.

The only check I have observed or interpret from any of Doctor Dixon's figures is that due to the reflection of sound from the end of tube. At the start the apparent flame-velocity is made up of the velocity within the gas plus the mass movement of the gas itself. The reflected sound-wave checks this mass movement for a short interval, even making it negative; but has no other effect upon the progressive movement of the flame within the gas than that the momentary differences of pressure may affect its velocity, by a rise of temperature.

Temperature has a profound effect upon all chemical reactions. Over the range of about 100 deg. cent. (212 deg. fahr.) where the most of the observations have been taken, the change in the velocity-constant is about 30 per cent per degree. With high temperatures the percentage-change would fall; but it would still be largely below any of the ignition temperatures, from 500 to 700 deg. cent. (932 to 1292 deg. fahr.); for very high temperatures, reaction velocities seem to be proportional to the pressure; for reactions at lower temperatures, pressure, without a corresponding temperature rise, seems to have little effect.

Since the elastic properties of gases and their densities determine their wave motion, it is to be expected from thermodynamic considerations that their reaction velocities will be closely connected with their physical properties. It seems, in fact, impossible to separate these two actions. It is greatly to Professor Dixon's credit that he has emphasized these relations. I think there are some chapters on sound that have not been written. I have seen a very nice photograph showing a reflected sound-wave from the end of a tube, meeting a flame-front where it has nearly reached constant velocity, detonation. The effect of the compression is beautifully shown by the bright spots; from which the flame-front then pro-

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ceeds at a constant velocity to the end of the tube. The sound-wave is refracted as it enters the highly heated and rarified gases behind this point.

The photograph in the lower left corner of Fig. 22 looks like a most beautiful and interesting demonstration of a mooted question in sound. If the two waves finally coalesce, then they travel at unequal velocity. Is that possible? There is a short interval between them. Is it possible that this short interval furnishes enough difference of temperature to bring them into phase? Such a process could be used to measure the rate of cooling in these incandescent gases with great accuracy. Has Doctor Dixon found a new differential thermometer here? If once brought to phase, the waves will not separate again. This photograph has as much interest for the student of sound as for the chemist. There are some other interesting things about explosions in reference to sound that could be cited.

I think the expression "flame velocity" is often used to mean the velocity of combustion, which is a very different concept. Manometer readings have little to tell us about flame movement, but they give us a very considerable amount of valuable information about the rate of combustion.

The law of mass action probably acts as uniformly in quick as in slow reactions. The convenience of observing whether this is so or not is all in favor of the more common chemical processes or those largely confined to solutions where the retarding effect of the solvent and of the small temperature-range gives ample time for observation and measurement.

It is really remarkable that the major part of our laws in chemistry, certainly in thermodynamics, has been drawn from what we have supposed to be the simplest state of matter, the gaseous; yet the chemical processes taking place in gases are the least explored and determined of all. Against the bulk of other chemical reactions that we know fairly well, the percentage of gaseous reactions is almost negligible. Until there is sufficient evidence to the contrary we should look for gaseous reactions to follow the same general course as all others. Guldberg and Waage's generalization calls for a condition of constant reaction-velocity to be reached sooner or later in the reaction as determined by the driving force and those in opposition. Such a phase is one of the most characteristic properties of explosions. Berthelot was the

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first to point it out. Guldberg and Waage came to it as a generalization from the commoner reactions. The two are probably identical and follow the same laws throughout. Berthelot's attempt to identify these velocities with molecular velocities, doubtless following the inspiration of Clausius, is interesting; there seem to be some agreements, but the facts to draw from are meager. However well the lower limit of our thermodynamic scale seems established, the upper limit is not yet suggested. Gas reactions have a range through many thousand degrees; most reactions we are familiar with, through a few tens at most.

C. A. WOODBURY:—We were gratified to note the many points upon which our conclusions had coincided with those of Doctor Dixon. With regard to our one chief point of variance, namely, the cause of the arrest occurring in the flame movement, we are still unable to reconcile our results with his conclusions. Doctor Dixon suggests that we may find our difference to be mainly one of expression. We are, therefore, planning to submit a few of our photographs with detailed calculations of our results to him for consideration. By this means we hope to arrive at a true understanding of the phenomenon.

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CHICAGO MEETING AND DINNER

The meeting of the Society held in Chicago on Feb. 2 was not only a marked success but was the occasion of the first national sessions devoted to the operation and maintenance of automotive apparatus from an engineering standpoint. The technical sessions held during the morning and the afternoon were well attended. Vice-President B. B. Bachman was in the chair. N. J. Ocksreider, chief transportation engineer of the Packard Motor Car Co., gave an address on Engineering Analysis Applied to Truck Selling. He said that in this day of transportation engineering the requirements of each customer must be diagnosed accurately, eliminating economic waste due to wrong selling.

The Application of Steam Power to an Automotive Truck was the subject of the paper by L. L. Scott, who described the development and present status of a steam-driven 2-ton truck constructed by E. C. Newcomb and himself.

Capt. J. B. Haney, of the United States Ordnance Department, described the development of artillery automotive material during 1920, including the tractor hand-cart, reconnaissance tractor, Division artillery tractor, Corps artillery tractor, Army artillery tractor, heavy or 15-ton artillery tractor, tractor and trailer caissons of 1½ and 3-ton capacity, and self-propelled mounts for Division Corps and Army gun and howitzer.

The paper on Truck Fleet Operation, by N. J. Smith of the Consumers Co., Chicago, was very well received as showing the value of keen analysis and sound judgment in applying engineering principles to truck operation.

J. C. Thorpe, an engineer who has sold trucks and tractors in Illinois for many years, gave an address on Tractor Service Requirements, treating in turn the service, commercial and technical aspects.

The Need for Greater Service Accessibility in Car Design was treated by T. F. Cullen, managing editor of the *Automobile Trade Journal.* Mr. Cullen was formerly engaged in passenger-car service work and it is not surprising that his comprehensive discussion elicited much interest. Starting with the axiom that everything done to reduce upkeep and maintenance cost tends to

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increase the car-owner's satisfaction, items of expense were listed as follows in descending value: insurance, garage expense, repairs and adjustments, tires, gasoline and oil. Service reputation based on the cars now in use is rapidly becoming the predominating factor in resales. With 8,000,000 cars in use today the reduction of time necessary for service work by 2 hr. per car per year would make possible a saving of total upkeep expense per year of $15,000,000, in Mr. Cullen's opinion. In the preparation of his paper, the author made a survey of 40 cars representative of various schools of design, including those equipped with 4, 6, 8 and 12-cylinder engines and covering a wide price-range. He then rated the cars according to comparative accessibility in 25 different service operations, no attempt being made to cover all operations or extensive overhauls. On a basis of a par of four for each operation, Mr. Cullen rated the cars in percentages varying from 64 to 95, according to his view as to what the respective accessibilities should be; the percentage for engines with cylinders in a row being 83 as against 69 for V-type engines. In the last named connection it was pointed out that factors not related directly to service work must be taken into account in determining the all-around desirability of any passenger-car type of engine. L. H. Stellman, chief engineer of the H. H. Franklin Mfg. Co., expressed the opinion that in view of the omission of some service operations from Mr. Cullen's chart, the total percentages derived by him were somewhat misleading. Mr. Stellman offered the following points for consideration: Dividing parts to be lubricated into (*a*) engine, (*b*) fast-moving or heavy-duty, and (*c*) minor, such as brake-rods; all nuts and bolt-heads to be hexagon-shaped and mounted with sufficient clearance for use of commercial socket-wrenches; cap-screws to be sufficiently strong to withstand abuse in removal and reinstallation quickly and without undue care; where gaskets are used to prevent oil leakage, cap-screws to be sufficiently close together for an average mechanic to get a tight joint and freedom from bulging due to excessive tightening of cap-screws; readily replaceable felt washers in the front and rear wheels; localization of wear on small relatively inexpensive and easily replaceable parts; use of bushings or simple parts of low cost to take wear; arranging wiring so that it can be checked readily, preferably to have all wiring connected with central switchboard; and easy ad-

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justment of transmission and rear-axle bearings, with quick reassembly without consequent oil leakage.

Mr. Cullen dwelt at some length upon the value of factory engineers giving attention to the design of special tools and equipment for dealers' service-stations, to facilitate service work on new and old cars. The time is rapidly approaching when the factory engineering department will consider service-station equipment for the cars they build just as necessary as assembly equipment and machine tools for the factory. The service-man should be consulted in connection with car design, inasmuch as he meets the car-owners and knows their needs better than the designing engineer can know them under ordinary circumstances. Some factories have made it compulsory that engineers responsible for the design of a new car shall drive the car during the period of its development and do all necessary work on it themselves, the idea being that the lessons learned in this way should be used in improving the design.

President Beecroft described the "fixed-price" service system now being used more or less extensively in Wisconsin, whereby a car-owner calling at a service-station is apprised definitely what the shop charge will be before any adjustment or repair work on the car is done. Feeling that this is a step in the right direction, he said that the engineer should go out into the field for the purpose of interpreting and translating for his use the conditions of the environment in which the apparatus he designs works. It is his function to study conditions and meet them economically.

The dinner held on the evening of Feb. 2, which was attended by over 500 members and guests, was highly enjoyable and very instructive. In introducing First Vice-President H. L. Horning, who acted as toastmaster, President Beecroft called attention in a forceful manner to the importance of the work of the Society as evidenced by its personnel and exemplified in its great activities centered about the internal-combustion engine, in the design and production of passenger cars, motor trucks, tractors, house lighting apparatus, stationary engines, motorboats, motorcycles and aircraft.

Mr. Horning made a plea for a more complete realization that basic worth of character is the world's greatest asset and that no individual can hope to survive industrial difficulty unless he has that personal integrity upon which every business man must depend. In connection with re-

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search, he said that the man who is not sufficiently versed in physics, chemistry and thermodynamics to locate and understand the things that are causing difficulty in his work will fail; that the firm that makes good will be the firm that knows the job through and through.

Prof. J. Paul Goode, of the University of Chicago, gave a masterly address on America as a World Power, presenting many novel charts bristling with statistics that brought home in a very vivid manner the amazing potentialities of this Country and the tremendous individual and national responsibilities involved therein. It is pretty certain that few if any of the members ever witnessed such an array of coordinated facts in chart form relating to the wealth and commerce of this Country from its inception. Professor Goode said that America is great enough to be generous and wise enough to be just, and expressed the hope that our great opportunities and powers will be used henceforth in such manner that we shall deserve the respect and gratitude of all men for all time.

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RECENT DEVELOPMENT OF ARTILLERY AUTOMOTIVE MATERIEL

By Capt J B Haney[1] U S A

The author describes the progress of the work of artillery motorization in the year 1920, beginning this with a statement of the recommendations made by the Westervelt Board, appointed by the War Department to make a study of the subject, for the development of track-laying equipment, the use of wheeled trailers on which the track laying materiel could be loaded and towed over good roads by trucks, and in regard to the possibility of incorporating trailer wheels in the track-laying vehicles themselves. The various types of materiel constructed during 1920 are illustrated, described and commented upon, inclusive of heavy tractors, supply and maintenance equipment, gun-mounts and tanks. It is stated that the recommendations of the Westervelt Board will be the basis of armament development for some time to come.

Last year at the Chicago Truck and Tractor Meeting George W. Dunham read a paper entitled Artillery Motorization as Related to Caterpillar Traction[2], in which the problem of artillery motorization and the achievements in that line up to the end of 1919 were presented in a clear and convincing manner. In this paper I will undertake to describe briefly the progress of the work of artillery motorization in the past year. Mr. Dunham referred to the Westervelt Board, appointed by the War Department to make a study of the armament, calibre and types of materiel, kinds and proportion of ammunition, and methods of transport of the artillery to be assigned to a field army. This Board made a very complete report based on the experiences of the Allied Armies during the war, and its recommendations will be the basis of armament development for some time to come. Without going into detail it will be sufficient to note that the development of the following track-laying materiel is directly recommended by the report of this Board:

Tractor hand-cart
Reconnaissance tractor
Division artillery tractor

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[1] Ordnance Department, Washington.
[2] See Transactions, vol. 15, part 1, p. 644.

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FIG. 1—EXPERIMENTAL TRACTOR HAND-CART WITH A LOAD OF 310 LB. BEING PULLED OVER SOFT WET GROUND BY ONE MAN

Corps artillery tractor
Army artillery tractor
Heavy or 15-ton artillery tractor
Tractor caissons of 1½ and 3 tons capacity
Trailer caissons of 1½ and 3 tons capacity
Self-propelled mounts for the division, corps and army gun and howitzer

The Board also recommended investigation of the use of wheeled trailers on which the track-laying materiel could be loaded and towed over good roads by trucks, and of the possibility of incorporating trailer wheels in the track-laying vehicles themselves.

The various types of materiel constructed in the past

FIG. 2—EXPERIMENTAL TRACTOR HAND-CART FLOATING WITH A LOAD OF 360 LB.

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year will be taken up in the order given. The first of these is the tractor hand-cart recommended by the Westervelt Board in approximately the following terms:

> A cart with caterpillar tracks to be pushed or drawn by one or two men, to be used as an ammunition carrier in stabilized warfare, or for carrying other miscellaneous supplies, which due to local conditions would otherwise have to be carried by men on foot.

A suitable mechanism for applying power direct to the track, which would enable the cart to be worked over steep grades or terrain over which two men could not draw or push it was also to be provided. Specifications were drawn up for this tractor hand-cart and bids on

FIG. 3—EXPERIMENTAL RECONNAISSANCE TRACTOR

designs asked for, but no bids being obtained the design work was assigned to the engineering offices of the Tank, Tractor and Trailer Division of the Ordnance Department. In the absence of any data on track-laying vehicles of this type an experimental model, shown in Fig. 1, was constructed rather for the information of the designer than with the idea of producing a vehicle for test by the Ordnance Department or the service. It is 36 in. long and 24 in. wide overall. The load capacity is 200 lb. The body is watertight and of sufficient displacement to float the cart with a full load, as can be seen by referring

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FIG. 4—RECONNAISSANCE TRACTOR WITH LOAD IN DEEP WATER

to Fig. 2. The estimated weight of a cart of this type was 125 lb., but the weight of this preliminary model is somewhat greater. The design shown here has a pulley and ratchet mechanism, by which power can be applied to the tracks in accordance with the specifications. This model proved successful in the various tests and demonstrations to which it was subjected, but it has been decided that the limited service a cart of this type can give will not justify its development at this time.

The ¼-ton or reconnaissance tractor shown in Fig. 3 is intended to fill the gap in motorized artillery left by the horse of the individual mounted man, as it is not practicable to combine horse and motor transport in the

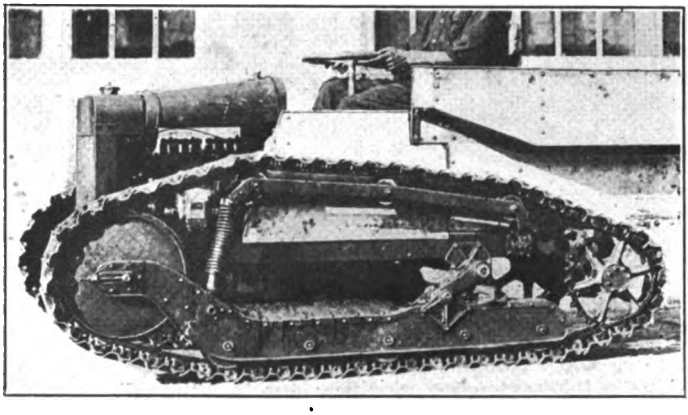

FIG. 5—ANOTHER TYPE OF EXPERIMENTAL RECONNAISSANCE TRACTOR

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same unit. The motorcycle has been tried for the transport of officers, scouts, signal men, etc., but as it requires fairly good roads, its use is limited. The recommendations of the Westervelt Board were for a reconnaissance tractor weighing 1200 lb. with a load capacity of 500 lb. and a maximum speed of 15 m.p.h., but both types of vehicle produced have exceeded this weight limit considerably. As can be seen from Fig. 4, this tractor will operate in water of considerable depth. Its body has sufficient displacement to float the tractor with its load, while its weight is such that it can cross on improvised bridges, trenches or ditches too wide for it to cantilever. Power is furnished by a Militor motorcycle engine fitted with a Sirocco fan to supply air for cooling. The specified high speed is 15 m.p.h., but rates in excess of this have been maintained for short periods.

The striking feature of this tractor is the track invented by Lieut.-Col. A. M. Chase, who is now in charge of the Syracuse Engineering Office of the Tank, Tractor and Trailer Division of the Ordnance Department. This track has been used also on tractor carts designed by Colonel Chase. It will, it is thought, make possible the construction of small vehicles of the types just described without exceeding reasonable weight. This track consists of two fiber strips connected at intervals by arch-shaped metal pieces which bear on the rubber-tired wheels. Steps are being taken to subject this type of track to a test that will determine its durability.

A second model of the reconnaissance tractor is shown in Fig. 5. This has not yet been given a test or demonstration, so there are no data as to its performance. It has a water-cooled engine and a metal track. A similar model is being built, but with an air-cooled engine and a combined fiber and metal track. When the second model is completed, tests will be made to determine the ability of this type to fulfill the requirements of the Westervelt Board.

Heavy Tractors

Next is the Division or 2½-ton tractor. Its name indicates the ideal weight of the size of vehicle wanted but so far this has not been realized. The first Division tractors were built in 1918 but were finished too late to be of service during the war. Before putting them into service the Ordnance Department found it necessary to make rather extensive modifications to eliminate certain defects, so none of these tractors actually went into

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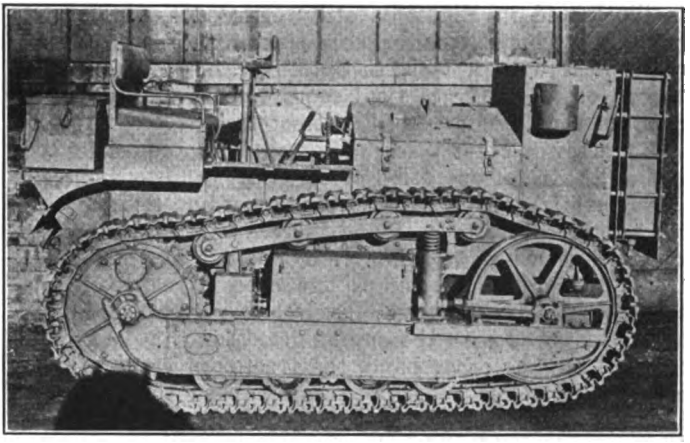

FIG. 6—DIVISION ARTILLERY TRACTOR

service until 1920. As now constructed the tractor weighs 7700 lb. It has speeds ranging from 5 to 9 m.p.h. at normal engine speed but a rate as high as 12 m.p.h. has been maintained for short periods. This tractor which

FIG. 7—TWO AND ONE-HALF-TON DIVISION ARTILLERY TRACTOR DESIGNED BY ORDNANCE DEPARTMENT CLIMBING

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is illustrated in Fig. 6 is still regarded as an experimental type but several organizations have been equipped with them with a view to obtaining more definite information as to the tactical requirements of high-speed tractors for Division Artillery materiel.

A tractor or other track-laying vehicle intended for use in the theatre of operation of an army requires sufficient power available at the tracks to move it and its load over the terrain likely to be found there. It will be required to cross trenches, to climb into and out of shell holes, travel through mud-swamps and cross streams of considerable depth. This mobility is best secured by a very low track speed with the engine developing its maximum torque. On the other hand, the tractor must be capable of sustaining the same or greater speed than a truck train when operating on good roads, assumed as 12 m.p.h. In case of rapid concentration of troops or surprise attacks, when the troops are moved in trucks, the artillery must accompany them and be ready to go into action with the infantry; otherwise valuable time would be lost.

The Ordnance Department designed and built the Division Artillery tractor model of 1920 shown in Fig. 7 in which the defects of the earlier models were avoided and the requirements for higher speed were successfully met. This tractor was exhibited at the Summer Meeting of the Society at Ottawa Beach, Mich., in June, 1920, and a very complete description by the designers, G. R. Pennington and S. K. Wellman, was published in THE JOURNAL[3]. It has speeds ranging from 1 to 15 m.p.h. with the engine running at normal speed, and by speeding up the engine it has attained 18 m.p.h. Every effort has been made to build this tractor to operate with the least practicable noise, rubber-cored track rollers being used. It is waterproofed to operate successfully in water 4½ ft. deep at a speed of 7 m.p.h. While the track-supporting system operates satisfactorily, to offset the effects of loading the track, it has been found that it absorbs considerable power; experiments are under way in this connection. The formal test which the tractor is now undergoing will give sufficient data to determine whether the system mentioned will be retained.

SUPPLY AND MAINTENANCE

With respect to supply and maintenance the ideal Artillery tractor would be one produced in quantity for com-

[3] See THE JOURNAL, October, 1920, p. 321.

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mercial uses. Unfortunately, however, three factors on which the Army places considerable stress, speed, waterproofing and quiet operation, do not as yet enter decisively into the design of commercial tractors. If commercial tractors fulfilling all the requirements of the Army are not obtainable, the next best thing is to find one that with the fewest modifications will meet them approximately. We have not found such a one, but one is being developed that seems very promising. Its development belongs to the current year, however, and not to 1920.

Unless an emergency should arise in the near future, it is intended not to build any more 5 and 10-ton tractors of the type now in use, but to develop a new tractor of a

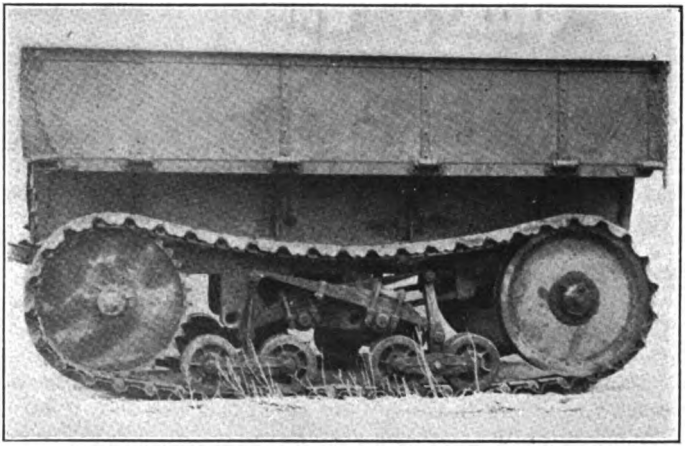

FIG. 8—ONE AND ONE-HALF-TON TRAILER

size between those of the Division tractor described above and the 15-ton tractor now under construction by the Ordnance Department to carry out the recommendations of the Westervelt Board. The latter tractor will be completed during the present year.

But little can be said in reference to tractor caissons. The types, both domestic and foreign, built during the war, were of too great weight to operate economically. So far nothing to replace them has been developed. Trailer caissons of ¾, 1½ and 3-ton capacity, the two last named recommended by the Westervelt Board, are under construction, but so far but one, a 1½-ton trailer, shown in Fig. 8, in which the track mechanism of the

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model 1920 tractor is used, has been offered for test. The absence of the track-supporting mechanism so evident in the tractor should be noticed.

The track-laying trailer problem is a rather difficult one. The question whether the body shall be supported at two points like a two-wheel cart or at three or four points is unsettled. Sharp turns are made with difficulty, as is indicated by the many broken drawbars. A decision as to the most satisfactory design can be reached only after thorough tests of different types.

Gun-Mounts

In the opening paragraphs of this paper reference was made to the recommendations of the Westervelt Board that wheeled trailers should be supplied, or trailer wheels incorporated in track-laying vehicles, in order that they might be towed at high speed, on good roads, by trucks. We have two types which obviate this requirement, the combined wheeled and track-laying and the high-speed track-laying vehicles. The first is exemplified by the Christie type, the second by the Division artillery tractor and the 75-mm. self-propelled gun-mount. The use of a separate wheeled trailer is no longer considered for moving tractors and self-propelled gun-mounts over good roads at high speeds.

The self-propelled gun-mount shown in Fig. 9 is a Holt caterpillar. The track rollers have rubber cores and are rubber-tired, the driving sprocket and idler are rubber-tired and the track has rubber pads inserted in each shoe. According to the builder this track has shown surprising durability; after 600 miles' travel it shows slight wear, and it is thought that it will outwear an all-steel track. We are told that this mount can sustain speeds up to 25 m.p.h. on good roads and makes no more noise when running at this speed than a heavy solid-tired truck. It has all the climbing and maneuvering ability of the tractor and will go, it is stated, anywhere its driver has nerve to take it.

The combined wheel and track-laying Christie-type mount for the 155-mm. gun has shown that it possesses merits to justify its issue to the artillery for a service test. One of these mounts was exhibited at the Summer Meeting of the Society at Ottawa Beach, Mich., in 1920. A view showing the mount crossing a sharp ridge or bank, in which the action of the track and track-supporting wheels is clearly brought out, is given

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FIG. 9—SELF-PROPELLED MOUNT FOR 75-MM. GUN CLIMBING A BANK

in Fig. 10. The latest design of this mount weighs 38,500 lb. complete with the gun, the overall length including

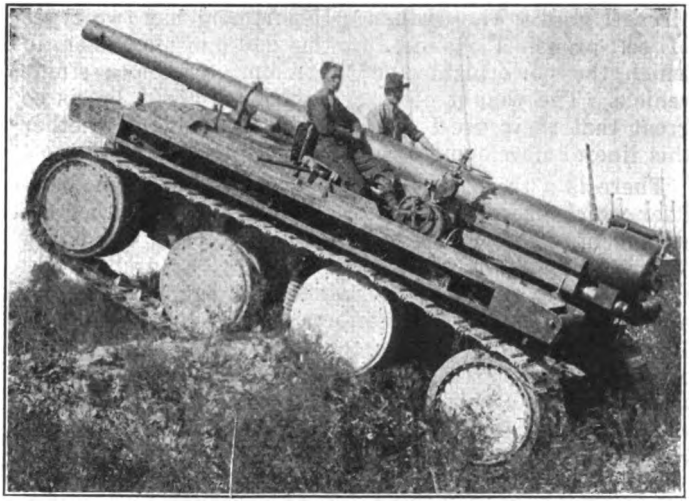

FIG. 10—COMBINED WHEEL AND TRACK-LAYING MOUNT FOR 155-MM. GUN

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the gun is 236 in. and the width is 112 in. The 120-hp. engine gives speeds ranging from 1½ to 15 m.p.h., the latter on wheels, the maximum speed on tracks being somewhat lower. Fifteen miles per hour can be exceeded under favorable road conditions by speeding up the engine.

This combined wheel and track-laying type of vehicle, while not considered as the ultimate, is a most interesting development, but its abilities have not been so rigorously tested as those of the tracklayer. When it is operated as a wheeled vehicle, it is steered by the front wheels, like a truck; as there is no differential, care must be taken in making short turns to release the clutch controlling the inner driving-wheel. The tracks can be taken off or put on in a very short time by a trained crew. When not in use they are carried on the track-supporting shelves on either side of the mount. Mechanism is provided for raising and lowering the center wheels of the mount. These are raised free of the ground when traveling as a wheeled vehicle, but lowered to take a large part of the load when operating on the tracks. When the track is in use the steering-knuckles are securely locked and the mount is steered by the clutches and transmission in the usual manner.

In addition to this 155-mm. mount there are being built mounts of a similar type for Division and anti-aircraft guns. The Ordnance Department has two types of self-propelled mount for the 240-mm. howitzer in which the powerplant and the mount are on a single vehicle. The weight of these vehicles, 106,000 lb., is so great that their use is limited. It is doubtful whether this line of development will be continued.

There is a third type of mount for the 240-mm. howitzer which has advantages that may justify further development. This is the gasoline-electric type, consisting of two vehicles illustrated in Fig. 11. The first carries the 150-hp. engine and generator and a supply of ammunition; the second is the gun-mount. Each unit has two 70-hp. electric motors, one for each track. When traveling on ordinary roads the two vehicles are coupled by a drawbar and connected by an electric cable. The second vehicle can be towed by the first or the motors of both vehicles used, as required by road conditions. If the going is so difficult that the power available will not suffice for both vehicles, they can be moved one at a time. Either vehicle can maneuver separately in bad going or

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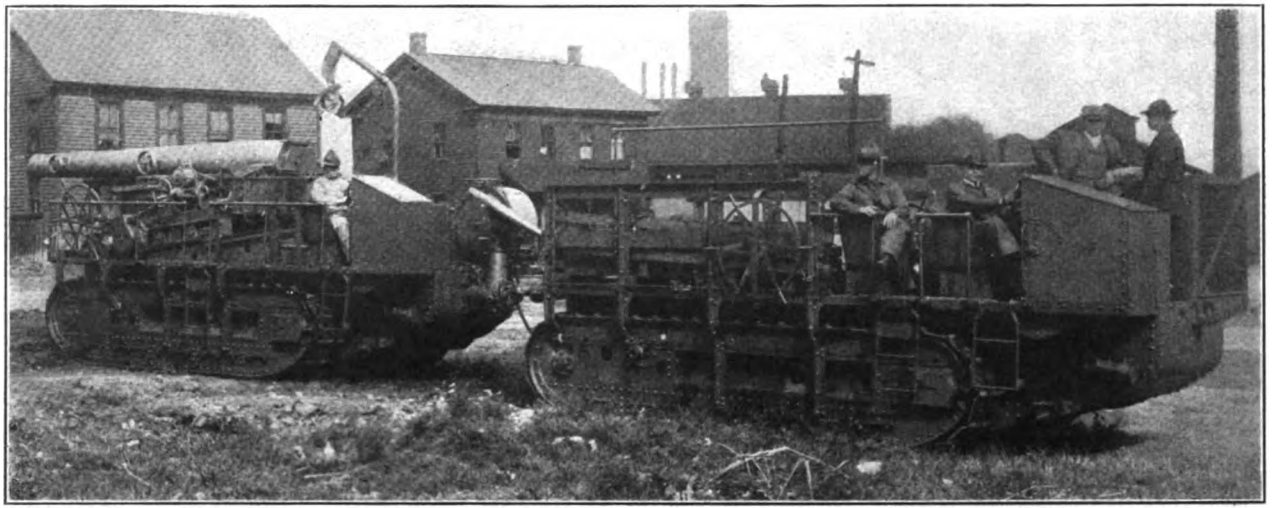

FIG. 11—GASOLINE-ELECTRIC SELF-PROPELLED MOUNT FOR 240-MM. HOWITZER

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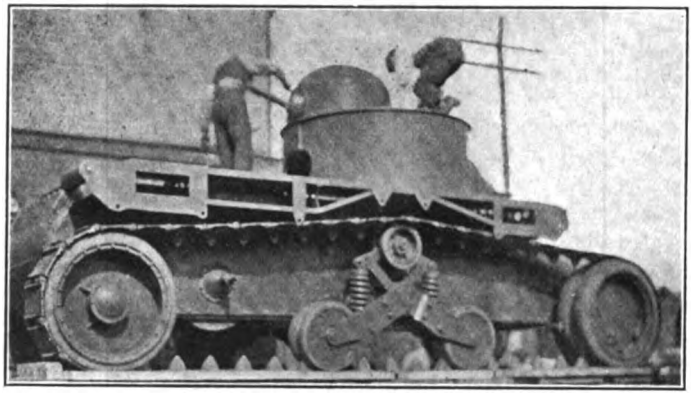

FIG. 12—COMBINED WHEEL AND TRACK-LAYING TYPE OF TANK

when being placed in firing position. About 200 yd. of cable is carried for this purpose. While this system of electric transmission has not been as thoroughly tested as the mechanical transmission, it offers a satisfactory solution for heavy self-propelled mounts.

TANKS

At the close of the great war the United States found itself with a small number of British tanks of various models, several hundred Renault 6-ton tanks of both American and French manufacture and 100 partially completed Mark VIII tanks. These last, weighing about 40 tons each, have been completed during the past year. They were designed primarily for crossing the extensive trenches of the Hindenberg line and while they did not get a chance to show what they could actually do, tests indicate that they are very successful. The pilot Mark VIII tank has a record of over 200 miles at an average speed of about 4½ m.p.h. without extensive repairs and,

FIG. 13—STAFF CAR WITH CABLE SUSPENSION TRACK

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with the possible exception of spark-plugs, relatively few replacements.

Tank warfare is so new that its demands have not crystallized, but the present tendency is toward a smaller tank than the Mark VIII but larger than the 6-ton Renault. Two such types are being produced. One, the combined wheel and track-laying Christie type by the Front-Drive Motor Co. of Hoboken, N. J., is shown in Fig. 12. This tank is about 22 ft. long overall, weighs about 16 tons and is equipped with a 120-hp. engine. It is expected to give a speed of 15 m.p.h. at normal engine speed, when traveling on wheels, on good roads. The larger center wheels of the 155-mm, gun-mount have been replaced by track-rollers, which resemble in principle at

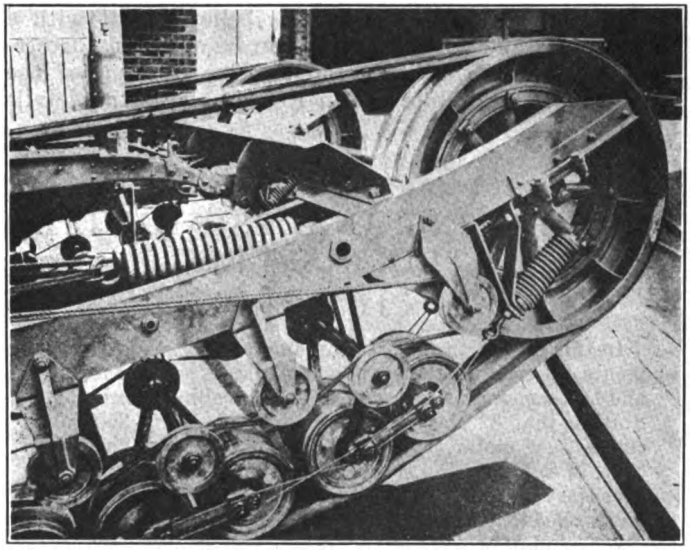

FIG. 14—DETAILS OF THE CABLE SUSPENSION TRACK

least those of the Ordnance Department's 2½-ton artillery tractor model 1920. As originally laid down this tank had but one center wheel on each side, in place of the two used in the 155-mm. self-propelled gun-mounts. This single wheel did not function in a satisfactory manner in the early trials and was replaced by the construction shown. These track-rollers are connected with the transmission so they can be raised or lowered by the driver with no more effort than depressing a pedal. This

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arrangement is to facilitate easing over sharp crests. It has performed some interesting stunts but has not been subjected to a formal test.

The Ordnance Department is designing and building two medium-sized tanks, one with a track of conventional design and the other with a cable-suspension track. The latter is the invention of Major Johnson, an officer of the British tank corps, and if rumors are to be believed British tanks equipped with tracks of this type are being run at speeds as high as 30 m.p.h. The Ordnance Department has at Aberdeen Proving Ground a White staff car equipped with a fabric track and cable suspension built in England from Major Johnson's design. Some idea of this form of suspension can be obtained from Fig. 13. This particular vehicle has not proved a success so far but it is believed that with a few changes and adjustments it can be operated successfully as an experimental vehicle. The close-up of the front end of the White car in Fig. 14 shows the details plainly.

ENGINEERING ANALYSIS APPLIED TO TRUCK SELLING

By N J Ocksreider[1]

In this day of transportation engineering, the requirements of each customer must be diagnosed accurately and the economic waste due to wrong selling eliminated. Stating that 32 classes of trades, divided into 350 subclasses, use motor trucks, the author expresses the view that, in applying the science of selling by analysis, it is necessary to know the cost of shipping every pound of goods, deducing in turn the correct size of truck for a given kind of work.

Referring to the fact that a truck cannot be designed to stand up under all conditions and that selling a truck which is unsuitable for a particular task means a dissatisfied customer, the author gives the opinion that a truck of mediocre merit will in many cases perform more satisfactorily than the best truck built operating under improper conditions.

The author makes a broad-minded and valuable contribution in his statement of the factors to be observed in determining the proper type and size of truck to meet a given customer's requirements in the most satisfactory

[1] Chief transportation engineer, Packard Motor Car Co., Detroit.

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manner, pointing out the many advantages derived from the making of unbiased recommendations and taking all steps possible to prevent overloading.

When I read, write or think of the automotive industry, I segregate, almost invariably, the progress of this field into three 10-year periods, those of (*a*) experiment, (*b*) development and manufacture and (*c*) marketing. Most of the older people in the industry can recall readily the old one-cylinder type engine, built that way supposedly so that engine trouble could be more "readily located." The second 10-year period showed considerable development in 2, 4, 6, 8 and 12-cylinder engines. We are in the third 10-year period now, marketing.

The old hit-or-miss idea of selling a prospective buyer of a motor truck anything he was willing to accept has disappeared. In its place the builder and the distributer have made great strides toward developing the selling of motor trucks on a thorough analysis basis. The builder must of necessity, to make his vehicles stand up, sell to the user the particular size truck that best fits the latter's requirements. In days gone by a truck salesman was too ready to sell a 2-ton truck to meet a particularly flexible requirement and as a result much trouble developed and brought about to a large extent lack of faith on the part of the user. When a truck is properly sold, it invariably gives far better results than a truck of the same size and make that has been improperly sold. The salesman must develop his method of selling along much broader lines. He must be able to observe and apply himself analytically. He must find the true problem as it exists and prescribe the proper remedy. Often an analysis of the customer's problems will show the salesman that the vehicle he sells cannot be used. He must then so inform the buyer and tell him what he should put in operation. The distributer and the builder must encourage this manner of selling through methods of training such as have been used by many of the larger manufacturers of specialties, including adding-machines, cash-registers and loose-leaf accounting systems. The motor-truck problem of today is not one of manufacture. There are questions of detail and refinement which the producer has yet to solve, but we know how to make remarkably efficient transportation machines. The great problem today, which invokes the honest consideration of the builder and the dealer as well as the user, is one of adaptability. What the user must decide is whether motor

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trucks or horses will best serve his needs, or whether a combination of these will produce the most desirable results.

The builder and the dealer must place themselves in the position of transportation experts, competent to give sound advice on questions arising in the field under discussion. Salesmen must be employed who are capable of analyzing a prospect's requirements and they must be encouraged to advise the prospect to act in his own interest, even at the risk of losing a sale. It is a great credit to the industry that there are cases on record where this attitude has been adopted and practised. It is obvious, of course, that the builder makes trucks to sell. It is precisely for that reason that he should see to it that his trucks are sold only where they can perform work most economically. This policy will inevitably develop "repeat" customers; any other will create enemies. The motor truck in its proper place is one of the greatest assets of modern life. Misplaced it is an economic waste.

Selling by analysis is not at all new. It has been in operation to my personal knowledge for more than 15 years; it is being used by nearly every large progressive industrial institution in America today. Some apply it more intelligently than others, but in a great majority of the cases the sales manager who is at all progressive realizes what the requirements of an analysis are. Charles M. Schwab very ably summed up the subject of selling by analysis in a single paragraph when he said

> The super-salesman is a man true to the interests of his customer. His supreme purpose is to quicken the imagination of the customer and make him see the true virtue of the goods he is selling. The super-salesman foresees the needs of his customer and provides against those needs in full faith that the event will justify his foresight. He puts his ideals above his profits, in full confidence that profits will surely accrue to fine ideals intelligently executed.

There is nothing especially difficult about selling by analysis. It does not mean that a man must be a technical expert. It requires only a good supply of common sense, mental alertness, a fair amount of imagination and adequate capacity for work.

Market Analysis

In a Packard distributership where market anaylsis has been profitably used, a truck salesman had the following conversation with his manager:

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I am very sorry to be $700 behind in my drawing account. That is a lot of money to pay out and get nothing in return, but I think conditions will change.

It is not the $700 that worries me, but the $6,000.

You haven't paid me $6,000. I am only $700 behind in my drawing account.

That's right. But what worries me most is the $6,000 in gross profit which we have lost due to the fact that you have not sold as many trucks in your territory as was anticipated. We assigned you part of the city with a thorough knowledge of its sales possibilities. We know how many vehicles are operated there now and in what lines of trade. We are further informed regarding the commercial activity in that section. We are not worrying about your drawing account, but about the business you are losing to competitors.

Do you know the potentialities of your territory for the sale of motor trucks in 1921?

How many of each size will you require during 1921, and in what months?

What trades in your territory use the majority of motor trucks?

Do you know what share of the business is going to your competitors, and in what trades?

How do you determine quotas for salesmen? Can you prove that your territorial assignments are based on an equitable division of sales possibilities?

Do you know from which trades you can secure the greatest results with the least expenditure of selling energy?

Knowing the Facts About the Market

One of the most valuable assets in a business is the selling organization, and its effectiveness will vary in accordance with the available knowledge concerning the market. To profitably distribute any commodity it is necessary to analyze the market to determine the factors affecting it today and to anticipate future conditions. The whole trend of distribution is away from the old methods of trial and error and toward greater dependence upon scientifically determined facts.

Prosperity depends very largely upon accurate knowledge of the market. If there is a market in your territory for 5000 trucks in 1921, and you have a quota of 500, you must sell 1 in every 10. But if you erroneously anticipate a market for 10,000 and confine your efforts to selling only 1 in 20, the end of the year will probably

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find you with a warehouse full of unsold trucks. Distribution based on accurate knowledge of a market will reduce sales expense, because it eliminates useless expenditure of selling effort and directs it where it will produce the greatest results. Scientific distribution cuts down footwork and increases headwork. You can continue the old hit-or-miss methods, but are you sure that your competitors will not improve their methods?

Making a Market Analysis and Its Results

Two basic types of market analysis have been successfully applied to date by Packard distributers. The first type depends upon a study of motor-vehicle registration records according to geographical location, trade classification and make of truck. The second type is a personal canvass of a territory to determine all actual owners of motor trucks and to locate all potential prospects. This article will deal with the registration method. Secure an accurate motor-truck registration-service covering your territory. The information usually given is the license number, make, capacity and engine number of the vehicle, together with the name and address of the owner. Transfer the records to a card index. When all the cards are typed they should be filed alphabetically according to the owner's name. In this way all the vehicles belonging to each company will be automatically consolidated, and fleets of trucks will be represented as a whole. The next step is either to rearrange these cards according to the line of business or to make a duplicate set for that purpose. If thought necessary, a third set can be made and arranged according to the make of truck. There is no end to the information obtainable in this manner.

Among the advantages of market analysis may be mentioned

(1) Knowing the trades active in each territory and estimating their probable requirements, your factory allotment can be accurately determined, thus preventing an excess of unpopular units and a paucity of units in demand
(2) Equitable assignments of territory to salesmen
(3) List of prospects for new trucks according to trades
(4) Prospects for second-hand trucks
(5) Comparative sales value of trades
(6) Active mailing-list according to trades
(7) Strength of competitors according to trades

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(8) Where the manufacturer's trucks predominate, the information is especially valuable for sales use
(9) In trades where competitors' trucks predominate, steps can be taken to correct this situation

THE DISCUSSION

CHAIRMAN B. B. BACHMAN:—I think Mr. Ocksreider summed up the situation rather tersely in recognizing that some of the competitors of his company are operating under the same general plan, possibly calling it by a different name. I am reminded in that respect of the similarity of what we have been pleased to call "efficiency engineering" in production lines. To draw a parallel, there is no question that in production lines the application of so-called efficiency methods has been of inestimable benefit, and that without the application of them our present system of production would be impossible. However, with the successes that have been accomplished and the presentation of principles which is possible only in the abstract, there have been those who considered themselves competent to take partial expression of principle and apply it in hidebound form. The results have been unfortunate. Selling is undoubtedly a science, just as is the design of an article or the production of it. As science has been slighted in engineering and in production, so it has been slighted in selling, but probably to an even greater extent. Mr. Ocksreider said that success in the application of correct methods depends upon the application of commonsense principles. It seems to me that in business engineering, production or selling, it all comes down to a basis of commonsense. Unfortunately, that is not such a common possession as its name indicates.

P. M. HOLDSWORTH:—In making analyses such as Mr. Ocksreider describes there must be some cases in which a Packard truck is not found to be the very best truck for the work. What would be the recommendation of the man that made the anlaysis in such a case?

N. J. OCKSREIDER:—We advise the customer frankly if a Packard truck is not fitted for his needs; or if horses are the better equipment. To give a concrete example, we had a case recently in which we analyzed the prospective buyer's needs. He thought that he could improve his hauling problem with the aid of a truck. Our salesman thought so at the time. After the analysis was completed we found that a truck, particularly of the size which we build, did not fit his needs. He had to do one

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of two things, retain his horse equipment or buy a ¾-ton vehicle. We reported accordingly and did not sell him a Packard truck.

MR. HOLDSWORTH: — Under certain circumstances, would you recommend an electric truck?

MR. OCKSREIDER:—Yes, we have done that. A particular instance is in the case of the Curtis Publishing Co., of Philadelphia. We analyzed its problem some time ago, recommended electric vehicles and it is now operating them.

S. E. BATES:—In the analyses are the different kinds of trailers taken into account and recommendations made accordingly?

MR. OCKSREIDER:—Yes.

MR. BATES:—There are probably 10 to 20 more kinds of trailers offered than of trucks.

MR. OCKSREIDER:—We take the requirements of the problem and prescribe absolutely the thing that we think will solve it with as nearly 100-per cent efficiency as possible. We have to recommend trailers in a large number of cases.

F. J. SULLIVAN:—What does the Packard company do when it makes a recommendation to a purchaser of trucks and after the trucks have been purchased the owner does not adhere to the recommendation, but overloads them for example?

MR. OCKSREIDER:—We protest sometimes; we try to follow the matter through, although it is difficult to keep a customer from overloading. When we make a survey we point out the consequences that can be expected and the inefficiency caused by overloading. We take into consideration deliveries and point out to the purchaser that he will hurt his own efficiency. If he persists, we are absolutely helpless. We often go to the drivers when they are out on the street with an overload and caution them.

J. G. CARROLL:—The work of the large electrical manufacturing companies in the transportation field is really pioneer work. For example, the installation of a mine-haulage system involves a thorough study of the customers' underground conditions. The companies do not recommend any equipment that would in any way increase haulage costs for the customer. If their own equipment does not fit, they tell the prospective customer so and recommend the size of the equipment he needs, the number of units and the method of installing the entire system. They give him also relative operating costs as

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closely as they can. This sort of procedure results in a transportation system that is as highly efficient as it is possible to make it. In the past some of the electric-truck companies have failed due to their not having analyzed the conditions under which the trucks had to operate. There were many complaints which gradually worked against the companies, until today very few of the original electric-truck firms are in existence. I have been connected with the application of motors in the electric-truck industry since it first started. I have seen companies grow up and drop away. Customers appreciate the advantage of being able to secure expert assistance from manufacturers in the solution of their transportation problems.

THE APPLICATION OF STEAM POWER TO AN AUTOMOTIVE TRUCK

By L L Scott[1]

The paper describes the steam-operated 2-ton truck developed by E. C. Newcomb and the author. It has a direct drive-shaft from the engine to a rear-axle worm, with a 5 to 1 gear-reduction at the axle, and is operated without any transmission or clutch. The engine has been simplified since the author's first report on it in 1919, the changes relating to valve-gear, crankshaft and cam design. After presenting illustrations and describing them, the author gives nine specific advantageous features in this steam powerplant and comments upon them, submitting charts of torque curves which are analyzed. The engine control, fuel, oil and water consumption are next described and discussed and the results of acceleration tests are then shown in tabular form, with comments thereon.

In connection with possible changes of detail in the design of automotive trucks, that have been brought to view by increased speed and the use of pneumatic tires, and because of the present status of the fuel situation, it occurred to me that a truck having an engine driving a rear-axle worm direct through a drive-shaft equipped with a 5 to 1 gear-reduction at the axle and that could be operated without any transmission or clutch, would be interesting to truck designers. A de-

[1] M.S.A.E.—Chief engineer, Standard Engineering Co., St. Louis.

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scription of the steam-operated 2-ton truck developed by E. C. Newcomb and me, which offers a solution to these problems, should consequently be of general interest.

In my previous paper, Steam Automotive System,[2] the details of design of the steam engine used on this 2-ton truck were described, but the engine has been simplified since that time. The changes in the construction of the engine relate to valve gear, crankshaft and cam design, and include many details that would not be of particular interest at present because of a lack of general knowledge of the problems involved. However, as very little is known concerning an engine that uses high pressures and temperatures for this kind of service, the details of its development can best be discussed thoroughly in a separate paper and I hope to do this later.

This truck was designed to carry a 2-ton load. The steam engine is located crosswise on the truck frame, as shown in Figs. 1 and 2, about where the transmission usually is on a truck driven by an internal-combustion engine. No transmission or clutch is used. In our latest design the engine is located just at the rear of the driver's seat and can be mounted either horizontally or vertically as desired. By so locating the engine the steam and the exhaust lines are shortened and so is the shaft that drives the radiator fan, but the axle drive-shaft is thus made longer. The engine shaft is directly connected to the worm-driven axle through a drive-shaft. The camshaft, which operates the valves, is adapted to be shifted axially for controlling the cut-off and reversing the engine when backing the truck. A pedal operated by the left foot, similar to the clutch pedal on a truck driven by an internal-combustion engine, is used to shift the cam.

A sectional drawing of the engine, showing the crankshaft, drive-shaft and dynamo drive, is reproduced in Fig. 3, and the relative positions of the various parts of the system are brought out in Fig. 4. It is surprising how free this engine is from vibration and how smoothly it operates, even without a flywheel. The engine has two double-acting cylinders of 4-in. bore and 5-in. stroke and gives the same number of impulses as does an eight-cylinder internal-combustion engine, with the added flexibility of steam. It will be noted that a one-piece crankshaft is used, with plain connecting-rod bearings and two ball bearings for the journals. The engine flywheel

[2] See TRANSACTIONS, vol. 15, part 1, p. 392.

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FIG. 1—VIEW OF THE COMPLETE TRUCK SHOWING CROSSWISE POSITION OF THE ENGINE ON THE TRUCK FRAME

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serves as a pulley to drive the dynamo and affords an arm to which to attach the thermoid coupling. The front end of the dynamo shaft serves as a drive for the radiator fan.

Advantageous Features

The features of special interest in this steam power-plant are that

(1) Because the engine is directly connected to the drive-shaft, it cannot be run unless the rear wheels also turn. This prevents racing the engine or allowing it to run when loading or unloading the truck, which is a common practice with some drivers

(2) All kinds of road can be negotiated with the same gear-ratio between the engine and the rear axle

(3) The dump type of body can be used satisfactorily because a steam hoist can be installed if desired

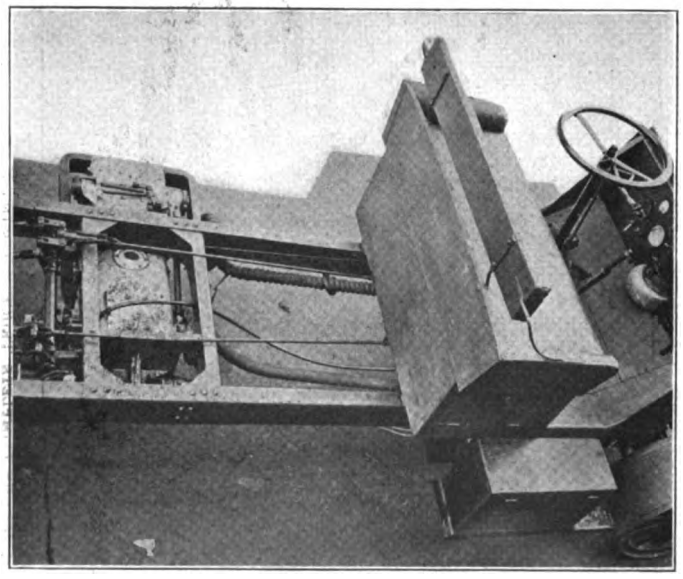

Fig. 2—View Looking Down on the Truck Showing Relation of Engine Location to the Driver's Seat

(4) Driving is more simple and the number of accidents should be reduced for this reason

(5) The rapid acceleration is conducive to safer operation at street corners and intersections

(6) No gear-shifting is necessary when starting

(7) Carbon does not collect in the engine

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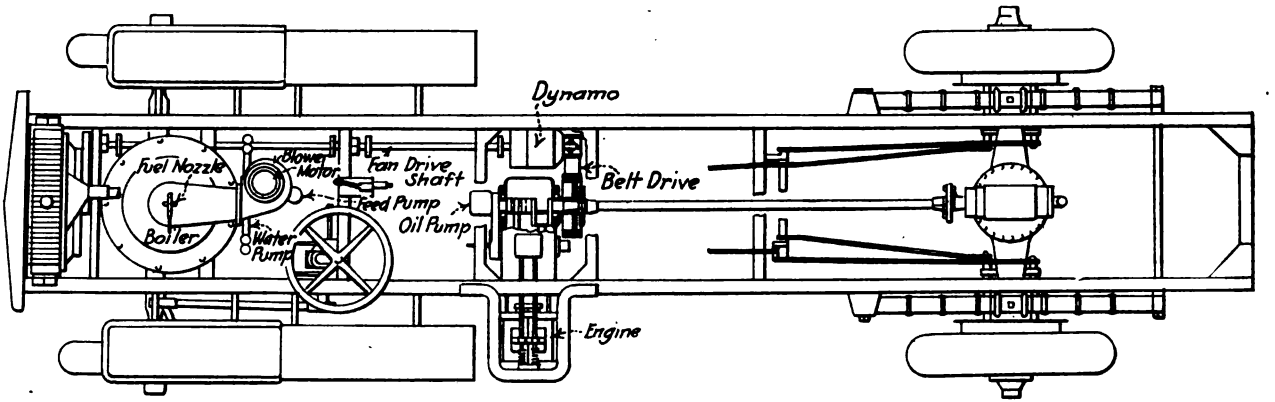

FIG. 3—PLAN VIEW OF THE COMPLETE TRUCK SHOWING THE LOCATION OF THE CRANKSHAFT, THE DRIVE-SHAFT AND THE DYNAMO

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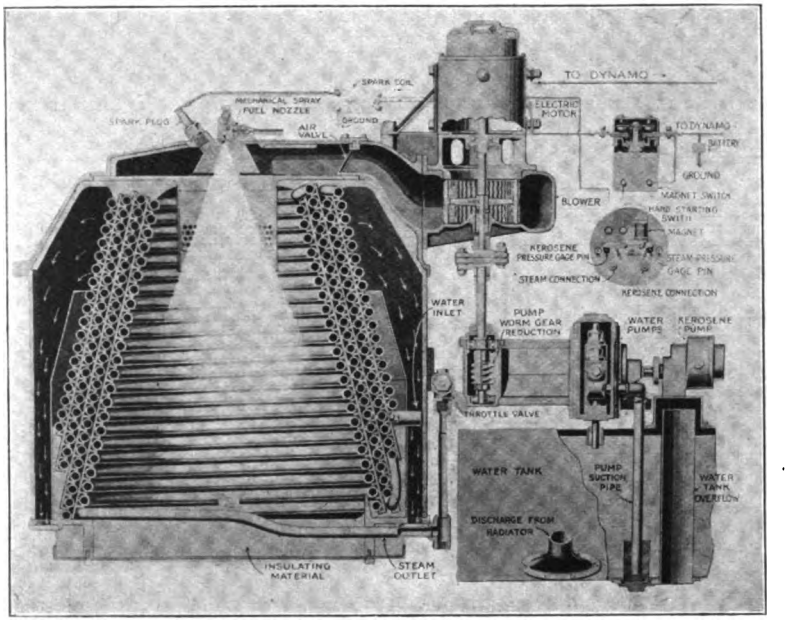

Fig. 4—The Relative Position of the Different Parts of the System

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(8) The valves do not require regrinding
(9) Dust cannot be sucked into the engine and the truck should, on this account, remain operative for longer continuous periods than in the case of trucks driven by an internal-combustion engine

The boiler is located under the hood as shown in Fig. 5. Steam can be raised in less than 1 min. from a cold start. No effort is required in getting up steam other than turning a switch. No stuffing-boxes are used on the engine or pump. The water and fuel-pumps are operated by an electric motor, which is controlled by a switch on the steam gage.

Fuel oil, gas oil, kerosene, gasoline or any mixture of these fuels can be used. This makes possible the utilization of 80 per cent of the crude oil available. It is possible also to use powdered coal or coke as a fuel. The fuel is cleanly and completely burned, without experiencing any of the long list of troubles common to the explosive type of engine that are due to the present grade of gasoline.

The lubricating oil, which can be of the same grade as that used to lubricate internal-combustion engines, is carried in the crankcase of the engine. All parts in the

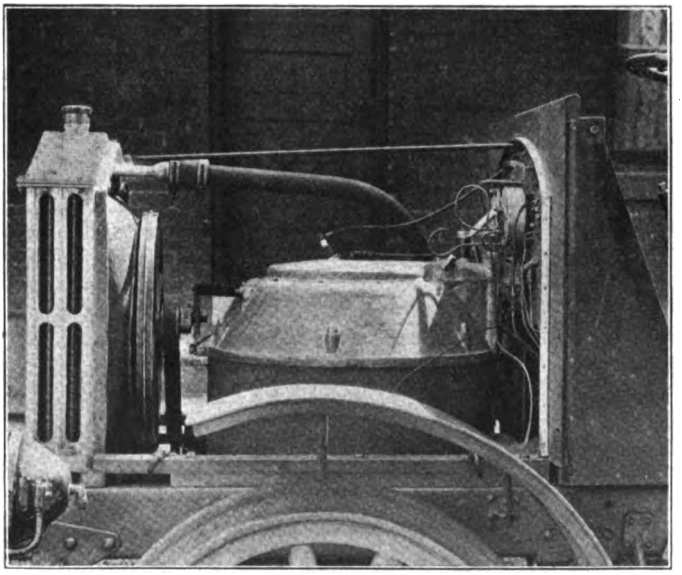

FIG. 5—THE BOILER IS LOCATED UNDER THE HOOD

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crankcase are lubricated by splash. A small valveless oil-pump is used to pump oil from the crankcase to the steam line for lubricating the cylinders. The engine is of the poppet-valve type, and the valves require little or no oil.

The weight of this steam powerplant, including the engine, boiler and water, is practically the same as that of an internal-combustion engine powerplant of similar capacity, inclusive of the cooling system, clutch and transmission.

Torque Curves

Fig. 6 shows the characteristic torque curves of the internal-combustion engine and the steam engine powerplants, the two becoming identical at 1000 r.p.m. The

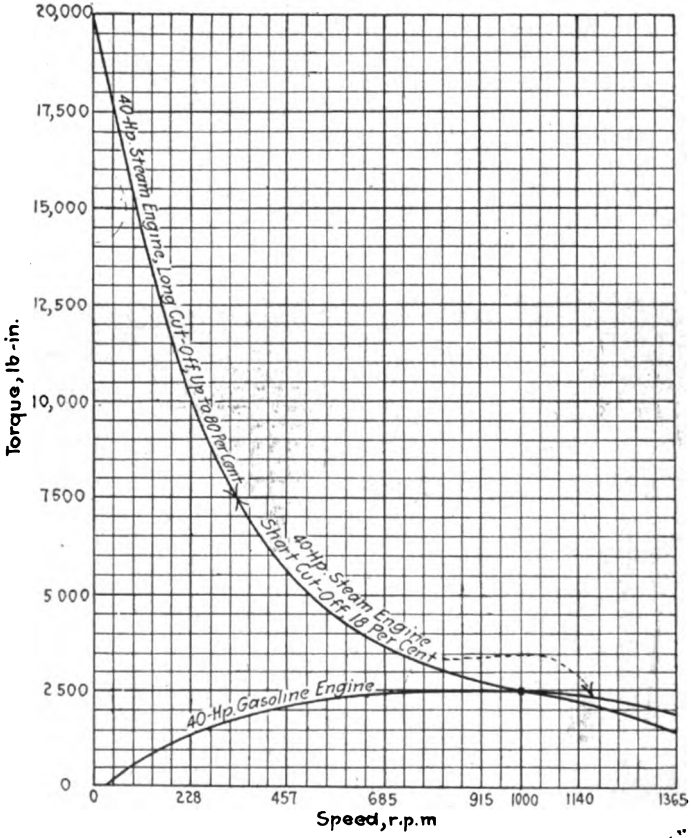

Fig. 6—Characteristic Torque Curves of a 40-Hp. Internal-Combustion Engine and a Steam Engine Developing the Same Power

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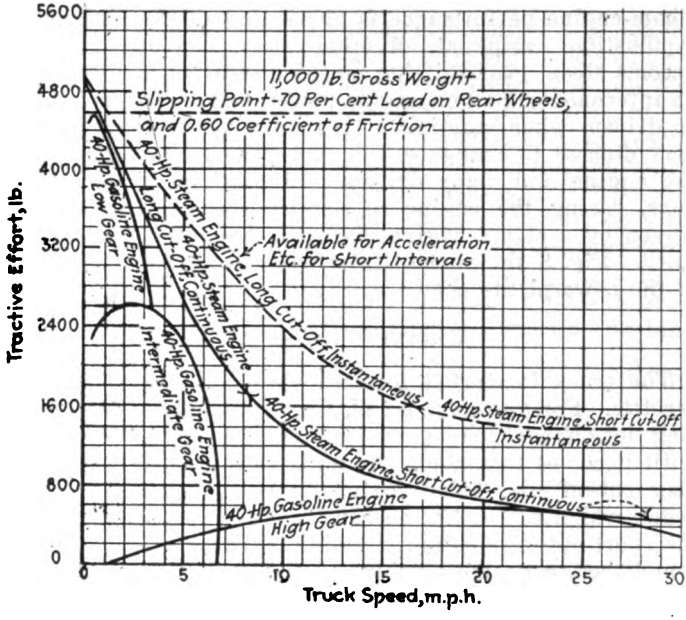

FIG. 7—THE RESPECTIVE PERFORMANCES OF THE STEAM AND INTERNAL-COMBUSTION ENGINES WHEN APPLIED TO A 2-TON TRUCK HAVING A GROSS WEIGHT OF 11,000 LB.

particularly noteworthy feature is the ability of the steam engine to maintain a constant horsepower over almost the entire range of speed on the short cut-off, thus insuring maximum economy of operation above 300 r.p.m.

Fig. 7 shows the respective performances of these powerplants when applied to a 2-ton truck having a gross weight, when loaded, of 11,000 lb. Each is a high-speed truck equipped with 8 x 40-in. pneumatic tires on the rear wheels and has a 5 3/7 to 1 gear-ratio in the axle. The low and the intermediate gear-ratios between the engine and the rear wheels are assumed to be 50 to 1 and 25 to 1 respectively. For purposes of illustration, only three speeds are assumed. This is not in accordance with usual practice for this particular case, but it introduces sufficient gear-changes to demonstrate the method of operation. The efficiency of the worm-gear axle is assumed to be 90 per cent in each case and the transmission also is assumed to be 90 per cent efficient.

It is noteworthy that the steam-engine curve in Fig. 7 meets the tractive effort of the truck equipped with the internal-combustion engine at 22 m.p.h. and that the

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steam-engine performance is above that of the internal-combustion engine at all other points. When grades become steep, gear-shifting must be resorted to in using an internal-combustion engine powerplant. With a truck so driven, when starting a load up a heavy grade it is very difficult to change to a higher gear without stalling the engine and many drivers will continue to use low gear, racing the engine to acquire speed. The truck driven by a steam engine does not encounter this difficulty. Fig. 8 shows the performance on grades of each of the powerplants shown in Fig. 7.

Engine Control

The truck is started forward simply by opening the throttle. For an extreme pull, the cam is shifted into the long cut-off position by pushing the left pedal forward until it comes to a stop. As no latch is provided in the long cut-off, the driver naturally will release the left pedal, which will shift the cam to the short cut-off. In the short cut-off position any kind of running can be accomplished, even the climbing of a 14-per cent grade at 8 m.p.h. When extreme grades are encountered, the cut-off can be lengthened by pressing the left pedal forward.

To reverse the engine for backing the truck, the left pedal is moved forward until it strikes the long cut-off stop; then, by tilting the pedals slightly, it will clear the long cut-off stop and can be pushed forward until it stops. This is the reverse position. It is possible to use the reverse as an emergency brake, thus eliminating the necessity of equipping the truck with airbrakes.

All parts of the powerplant are accessible. The boiler top can be removed and the coils exposed within a few minutes. The spark-plug and the fuel-spray nozzle are located at the top of the boiler and can be removed quickly. Access to the fuel and water-pumps is afforded by the ample space allowed under the foot-boards. The gages are mounted on the dash and when the hood is raised their connections are exposed. The two connecting-rod bearings are the only ones in the engine that are adjustable and they can be reached easily by removing the back cover of the engine case. The engine can be removed from the truck within 10 min. It should be borne in mind that this type of engine requires no valve-grinding or carbon-deposit removal, and that it has no carbureter, magneto, spark-plugs and the like.

In view of the fact that this truck has no transmission,

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in the accepted sense of this term, there is a material saving in power. This type of steam engine shows about the same efficiency at one-quarter load as at full load, which is much better performance than that of the internal-combustion engine. I understand that gearbox efficiency becomes as low as 70 per cent in some instances.

With a gear-reduction at the rear axle of from 5 to 5½ to 1, it is possible to slip the rear wheels on a dry pavement when the truck is fully loaded. When the truck is traveling 25 m.p.h., the engine speed is about 1200 r.p.m. The high torque at low engine-speeds makes the gearbox unnecessary and allows this plant to fit into the high-

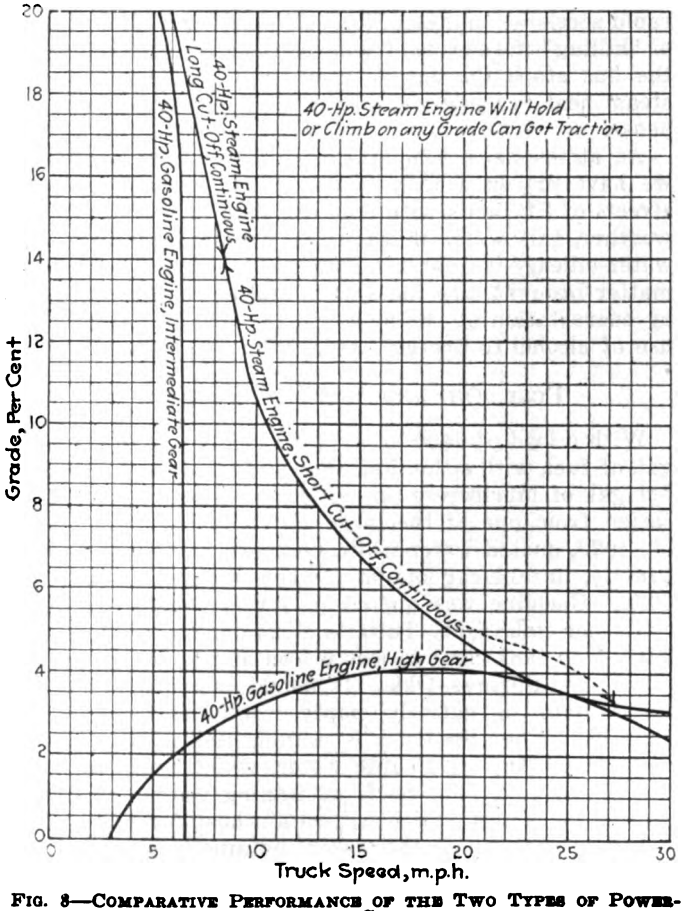

FIG. 8—COMPARATIVE PERFORMANCE OF THE TWO TYPES OF POWER-PLANT ON GRADES

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speed pneumatic-tired truck without excessive engine speed and without transmission or clutch.

As an example of the advantage of eliminating the transmission and clutch on trucks used in bus service in some of the large cities as many as 1000 stops per day are made, requiring several thousand gear-changes. Frequent stops and starts with a heavy load are very destructive to a truck equipped with an internal-combustion engine, with which a transmission and a clutch are required. There has been considerable comment on the adaptability of the internal-combustion engine driven truck to bus service. The steam plant is ideal for this service, some of its advantages being smooth operation, rapid acceleration, flexibility, self-starting with no chance of "killing" the engine at some critical moment, that when the bus stops the engine also stops, and that exhaust steam heat for cold weather is available at no extra expense.

At atmospheric temperatures of 85 to 90 deg. fahr., we have driven a fully loaded truck 700 miles on the streets of St. Louis with only one tank of water. In cool weather, this water mileage is increased greatly. Long water-mileage is important because it reduces the foreign matter brought into the system and no trouble is caused by encrustation of the boiler tubes; also, it permits the use of alcohol to prevent freezing in cold weather.

Fuel, Oil and Water Consumption

With a load of 4400 lb. we get from 5½ to 6 miles per gal. of fuel, with either kerosene or fuel oil, and 300 miles per gal. of lubricating oil, with solid tires. A communication from one of the large oil companies dated Sept. 30, 1920, quoted water-white kerosene of 41-deg. specific gravity, in tank-car lots, at 11 cents per gal. f.o.b. Tulsa, Okla. Gasoline was quoted in similar quantities at 23 cents per gal. f.o.b. Tulsa, and 24-deg. specific gravity fuel oil in tank-car lots was priced at 8¼ cents per gal., f.o.b. Sand Springs, Okla. It should be remembered that the radiator is entirely empty when the truck is not running. When the truck is running the radiator is used to condense the steam into water, which then runs into the water-tank. The parts containing water are located around the boiler, which will retain heat for 12 hr.

In localities where the water contains large quantities of calcium and magnesium, it can be run through a small tank containing a mineral substance resembling clay or

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TABLE 1—ACCELERATION TESTS—CHASSIS ONLY—NO LOAD[3]

From Zero Speed to M.P.H.	SOUTH Time, sec.					Average Time, sec.	Acceleration, m.p.h. per sec.	NORTH Time, sec.					Average Time, sec.	Acceleration, m.p.h. per sec.
	1	2	3	4	5			1	2	3	4	5		
10	3.6	..	3.0	2.7	3.0	3.08	3.25	3.0	3.0	3.0	2.6	2.7	2.87	3.49
15	5.4	..	4.0	4.7	4.4	4.62	3.25	4.0	4.8	4.4	4.4	4.4	4.40	3.41
20	7.2	7.2	6.8	6.2	6.7	6.82	2.93	5.8	7.8	6.9	7.4	6.4	6.86	2.92

[3]Using long cut-off for starting; then using short cut-off. Run was made on level ground.

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shale that is mined in South Dakota and makes the water softer than rain water. A tank of the size used in residences for heating water will soften 1000 gal. per day. This material is highly charged with exchangeable sodium. It is placed in a filter container in this condition and the water to be softened is passed through it. Having a strong affinity for the calcium and the magnesium in the water, the substance combines with these elements and gives up its sodium to the water in proportionate amounts. When the substance has become charged with calcium or magnesium, by a simple process of admitting a solution of sodium chloride the mineral substance is restored to its original state.

The saving in fuel and oil costs in comparison with the internal-combustion engine driven truck is evident, to say nothing of the saving in upkeep and repair due to the freedom from valve-grinding and carbon removal and to the elimination of the transmission and clutch.

On a 2-ton truck operating 60 miles per day, I estimate that a saving in fuel cost of $1 per day can be effected with the steam powerplant, thus saving $300 per year. The saving on lubricating oil at 25 cents per day would amount to $75 per year. Adding the saving because of the elimination of valve-grinding and carbon removal, about $30 per year, and the saving on general overhauling, about $100 per year, brings the total estimated saving to $505 per year.

Acceleration Tests

It is well known and generally recognized that any properly made steam car can accelerate much more quickly than can one driven by an internal-combustion engine. Attention is called again to the long cut-off

Table 2—Acceleration Tests—Chassis Only—No Load[4]

From Zero Speed to M.P.H.	Time, sec.		Average Time, sec.	Acceleration, m.p.h. per sec.
	1	2		
10	....	3.0	3.0	3.33
15	....	4.5	4.5	3.33
20	7.0	7.2	7.1	2.82

[4]Using long cut-off throughout.

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TABLE 3—ACCELERATION TESTS UNDER LOADED CONDITIONS—TOTAL WEIGHT, 11,065 LB.

From Zero Speed to M.P.H.	SOUTH Time, sec.					Average Time, sec.	Acceleration, m.p.h. per sec.	NORTH Time, sec.					Average Time, sec.	Acceleration, m.p.h. per sec.
	1	2	3	4	5			1	2	3	4	5		
10	5.0	4.0	4.2	..	3.2	4.10	2.44	3.4	4.2	3.2	3.8	3.2	3.51	2.85
15	9.0	6.4	7.2	7.0	6.0	7.12	2.11	6.0	6.5	5.8	5.9	6.0	6.04	2.30
20	12.0	11.0	11.7	10.3	11.1	11.22	1.78	10.0	10.0	9.5	8.9	8.8	9.44	1.95

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curve in Fig. 7. Acceleration tests of this truck were made at St. Louis by representatives of the Fifth Avenue Coach Co., of New York City, in November, 1920. Table 1 gives the results obtained in runs made with the chassis only, with no load, on a level street. The nominal diameter of the rear tires was 40 in. and their actual diameter 43 in. The speedometer was checked by counting the number of wheel revolutions per mile, this number being 938. The weights are as follows: Chassis, 5960 lb.; allowed for three passengers, 505 lb.; total weight, 6465 lb. The weight on the front wheels was 3100 lb. and that on the rear wheels 2860 lb. Under the same conditions as stated for the tests in Table 1, but using the long cut-off throughout, the results given in Table 2 were obtained.

In runs made after the body and the load had been placed on the chassis, the weight complete was 10,560 lb.; allowed for three passengers, 505 lb.; total weight, 11,065 lb. The weight on the front wheels was 3795 lb. and that on the rear wheels 6765 lb., without passengers. The acceleration test results are given in Table 3.

Alternate readings were taken of the blower periods, on and off, in runs made with the chassis loaded. The first run covered a distance of 4.95 miles with no stops. The blower was on 33.8 per cent, and off 66.2 per cent of the time. Under similar conditions, except that sixteen 5-sec. stops were made and that the distance was 5 miles, within the elapsed time of 19 min. and 19 sec., the blower was on 30.5 per cent, and off 69.5 per cent of the time. Table 4 gives the results of braking tests made on level ground.

Acceleration tests were made also on the grade locally known as Dead Man's Hill, the loaded weight being 11,065 lb. The run to the bottom of the hill is 7.75 miles, which was made in 24.84 min. at an average speed of 19.2 m.p.h. The speed at the bottom of the hill was 28 m.p.h. and the lowest speed on the hill, which has a 10-per cent grade and is a winding road, was 15 m.p.h. The results of these tests are given in Table 5.

A test was made on the failure of the spark to light the fuel spray. The spark-plug wire was disconnected from the spark-plug and the fuel was then turned on, thereby filling the combustion-chamber with kerosene vapor. When the fire was lighted again in the normal way, there was no explosion nor any smoke.

Another test was made on the failure of the fuel sys-

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TABLE 4—STEAM BRAKE TESTS

Run No.	Time. sec.	Distance, ft.	Speed, m.p.h.	Direction
Reverse, with no steam				
1	8.4	54	15	South
2	8.0	60	14	South
3	10.0	63	16	North
4	9.0	72	14	North
5	10.0	81	15	North
Reverse, with steam				
1	7.4	51	15	North

tem. The fuel was prevented from entering the combustion-chamber, thereby allowing the boiler to fill with water after the temperature was sufficiently low. After a short period the engine was cut off by the pressure gage. No damage whatever occurred.

A third test was made on the failure of the water system. The water was by-passed, thereby allowing the temperature to climb. The temperature reached 780 deg. fahr. and then the fuel was shut off by the solenoid valve.

Additional tests were made on Nov. 14, 15 and 16, 1920, the total loaded weight being 11,065 lb. in each case, with results as stated under Runs Nos. 1, 2, 3 and 4, on the following page.

Additional Run No. 3, made on fuel oil by Messrs. Wotton and Reese, was only for the purpose of testing the operation of the truck. It was limited to a 6-mile run, which was insufficient to warm up to efficient operation. No changes were made in the system in any way. We simply changed from kerosene to fuel oil and then

TABLE 5—ACCELERATION TESTS ON DEAD MAN'S HILL—TOTAL WEIGHT, 11,065 LB., GRADE 10 PER CENT.—WINDING ROAD

From Zero Speed to M.P.H.	Time, sec.			Average Time, sec.	Acceleration, m.p.h. per sec.
	1	2	3		
5	....	3.2	3.7	3.4	1.470
10	8.0	4.8	4.8	4.8	2.080
15	27.0	22.6	21.8	22.2	0.675

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ADDITIONAL RUN NO. 1

Total Distance, miles	49.9
Elapsed Time, hr.	3¼
Starting Time from Cold Boiler, min.	1
Temperature at 0.2 Miles Distance, deg. fahr.	650
Miles Run on Stored Steam	0.4
Number of Stops Made	178
Average Speed, m.p.h.	15.3
Water Used, gal.	1
Fuel Used, gal.	9⅛
Miles per Gallon of Fuel	5.49

Note:—After 3 hr. 3 min. the brush on the dynamo became loose.

ADDITIONAL RUN NO. 2

Total Distance, miles	35.5
Elapsed Time, hr.	1¾
Average Speed, m.p.h.	20.3
Maximum Speed, m.p.h.	32.0
Minimum Speed, Solomon Hill, m.p.h.	13.0
Fire Cut-Off on 10-Per Cent Solomon Hill Grade	3 times
Miles per Gallon of Fuel	6.59
Water Used, gal.	Slightly less than 2

ADDITIONAL RUN NO. 3

Total Distance, miles	6.2
Fuel Used, gal.	1

Note:—Appeared to run the same as with kerosene, with no odor or smoke.

ADDITIONAL RUN NO. 4

Total Distance, miles	30.9
Elapsed Time, hr.	1.6
Atmospheric Temperature, deg. fahr.	40
Average Speed, m.p.h.	19.3
Fuel Used, gal.	4 2/3
Miles per Gallon of Fuel	7
Water Used, gal.	1

started immediately, showing that almost any kind of fuel can be used without very much alteration. Many times I have changed from kerosene to gasoline, then to fuel oil and after that to a mixture of the three fuels, without any noticeable change one way or the other in operating performance.

Fig. 9 shows the truck equipped with a body and loaded. It will be noted that pneumatic tires are used. This truck has been run at 35 m.p.h., which was by no means the limit of its speed.

Table 6 gives the mileage per gallon of fuel and per

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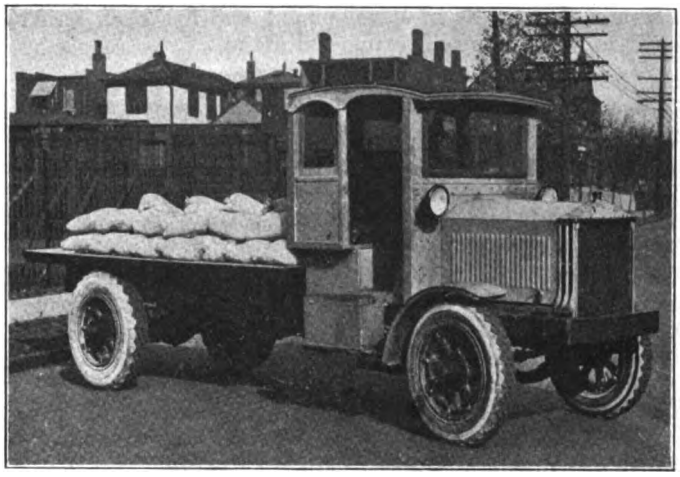

FIG. 9—THE LOADED TRUCK WHICH WAS USED IN THE TESTS

gallon of oil obtained with several different types of truck in tests conducted by a prominent oil-refining company.

FUTURE DEVELOPMENT

It is possible to equip this truck with some disengaging clutch for coasting. Such additional equipment will increase greatly the mileage that can be secured from unit quantities of fuel and feed-water.

We have a process for using steam to propel a truck or an automobile that will give a fuel mileage on our truck of from 18 to 20 miles per gal. of kerosene or fuel oil, if the details can be worked out in a way that is practical for use under ordinary operating conditions.

TABLE 6—MILEAGE PER GALLON OF FUEL AND OF OIL

Type of Truck	Capacity, tons	Mileage Obtained per Gallon	
		Gasoline	Oil
Bourne	2	4.72	91.3
White	2	5.21	45.3
Packard	3	4.30	128.5
White	5	3.14	20.1

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It is now in process of development and has been built, but it is still in the experimental stage.

THE DISCUSSION

A. L. NELSON:—With reference to Mr. Scott's discussion of the steam engine there is one point in comparing it with the internal-combustion engine which I think we should not fail to consider. Apparently he assumes that the inefficiency of the gasoline engine at partial loads will continue to remain as great as it has been. We should not assume that the internal-combustion engine will not be developed further. I believe that there is a very good chance of increasing the efficiency of the internal-combustion engine, not at full loads particularly but at the loads under which the engine is used in a truck. I think it would be well worthwhile to make comparisons with this in view.

WILLARD J. GRAMM:—How does Mr. Scott take care of the problem of freezing in winter?

L. L. SCOTT:—It is taken care of in one way by putting alcohol in the water. The water mileage in cold weather is such that this can be done without excessive cost. If the truck is being operated every day, it is not necessary to do anything for the reason that all parts containing water are under the hood. Freezing will not take place because in our particular arrangement there is about 4 in. of refractory material at the bottom of the boiler that retains heat for from 14 to 16 hr. In the event of freezing, the boiler, for example, will not be damaged in any way. The tubes will withstand a pressure of about 30,000 lb. per sq. in. and ice at that pressure is impossible. We are using alcohol right along in our touring car and our truck in cold weather.

Mr. Nelson spoke about the future. There are possibilities of all sorts of things. We have been working with the internal-combustion engine for many years and are making comparisons with what we have today. I mentioned also the possibility of future development of a steam plant that can show much greater efficiency than has been shown with steam plants to date. Taking the two types of apparatus as they are today, we are able to show a higher fuel-mileage on a lower grade of fuel. Of course, there are many other things to take into consideration besides that one point, such as the ability to burn the fuel regardless of its cost, the cost of oil, repair bills and the like.

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C. O. GUERNSEY:—I think that none of us should close our minds to any possible line of development that would permit us to use a greater percentage of the crude oil. I do not entirely agree with what Mr. Scott states. I have just made some rough calculations taken from figures given in Mr. Scott's tables. I may have made some assumptions that are not warranted but the figures I have are I think approximately correct. In one of the runs he reported 7 miles per gal. of oil with a total weight of, roughly, 5½ tons. I have assumed the road tractive effort required to be 60 lb. per ton, this being probably the requirement for an average country road, which I understand was the condition under which the truck was operated. Assuming 19,000 B.t.u. per lb. of oil burned, he is operating with an overall efficiency of somewhere around 11 per cent. That is neither particularly worse nor much better than we can get ordinarily from a gasoline engine.

Mr. Scott quotes some mileage figures for various trucks. I have no doubt that they are reasonably close to what is obtained in ordinary use in the hands of the average user, the trucks probably not being in the best of condition. However, Mr. Scott's figures are taken for experimental runs. I think for comparison we should give the gasoline engine the benefit of the same condition. It is easily possible with a conventional 2-ton truck without any special tuning up or anything of that sort to get from 7 to 9 miles per gal.

Undoubtedly, the steam engine does hold some possibilities. If Mr. Scott can develop a powerplant having an overall efficiency such as he mentions, we certainly should be very much interested. It seems to me that there is another line of development which possibly is being looked into under cover, but which has not been discussed to any great extent at the Society meetings; that is, the constant-pressure type of engine, possibly a combination of the steam and the internal-combustion engine systems. A theoretical diagram of such an engine shows a thermal efficiency of from 41 to 48 per cent, depending upon the compression used and other conditions. Such a system would have also the advantage of operating at a better efficiency under part than under full-load conditions. This is another avenue that we should not overlook.

R. B. HALL:—Has Mr. Scott used double or triple-

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expansion engines in his steam truck or experimented with them?

MR. SCOTT:—We have not. The only type of engine we have ever used is a simple uniflow or semi-uniflow double-acting engine. We have got steam rates below 12 lb. per hp-hr. This equals any test result that I know of with engines anywhere near the size of ours, including triple-expansion engines. We did not feel justified in using anything more complicated than the engine we have.

THE CARE AND MAINTENANCE OF MOTOR TRUCKS

By N J Smith[1]

The object of this paper is to point out some of the difficulties of motor-truck maintenance and to suggest lines of improvement. The buyer and user of a motor truck sometimes experiences disappointments due to the lack of coordination between the engineering and sales departments of a truck company. The term "service" is often misunderstood by the purchaser and misrepresented by the salesman, which results in dissatisfied customers. Salesmen should have accurate information on the service policy of their company and on all guarantees which they are authorized to make.

After rehearsing many of the difficulties encountered in truck maintenance, the author discusses in some detail the needed improvements in truck design, passing then to details of maintenance practice and methods of handling repairs. The results stated are those of actual experience, which prove that it is more economical to expend money for the prevention of trouble than to apply the same amount and more toward repairing defects.

The object of this paper is to point out some of the difficulties which present themselves in motor-truck maintenance, and to suggest, if possible, the lines along which improvement seems most needed, in order that these difficulties may be reduced to a practical minimum. Sometimes the buyer and user of a motor truck experiences disappointments due to a lack of coordination between the engineering department and sales department of the truck company. The term "service" is often misunderstood by the purchaser of the truck and mis-

[1] Consumers Co., Chicago.

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represented by the salesman. With the exception of a few minor adjustments, service is sold and not given, but the buyer sometimes understands from the salesman that he is to receive free service, and so a misunderstanding arises. Again, salesmen sometimes make claims and promises which are unauthorized by the factory or the engineering department, and upon which they are not prepared to make good. A dissatisfied customer is likely to be the result, because he feels that things have been misrepresented to him.

All such trouble could be avoided by a better working agreement between the factory and the sales force. Salesmen should have accurate information on the service policy of their company, and on all guarantees which they are authorized to make. Furthermore, when the prospective buyer asks questions in regard to the engineering or mechanical details, the salesman, if unequipped with accurate information, should not draw upon his imagination, as is sometimes the case, but should get the desired information from the proper source. In this way a complete understanding between the seller and the buyer would exist from the start, and the latter would know exactly what the truck is supposed to do when he places it in service. It seems to me that this question of cooperation between the engineers and the sales department is an extremely important point in the psychology of selling and buying a motor truck. The buyer must understand exactly what he is buying, what it will do and the circumstances under which it will operate properly. The salesman is the man from whom he must get most of this information. The engineer is particularly interested in turning out a truck that will run a long time in a satisfactory manner. No matter how well his truck may be built, it will not stand abuse. Consequently, he is vitally interested in having the salesman educate the customer, and in making sure that the salesman, in his eagerness to make a sale, is not losing sight of the necessity of the truck finding a good home.

The country is full of trucks running at excessive speeds in spite of a 100-per cent overload; perhaps doing work that could be performed more economically in some other way. They are left in the garage over-night and take up their work again next day without having received the proper attention to make them fit for the street. It is a hopeless task for the poor truck, and extremely difficult for the best. The result is very likely to

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be an early journey to the junk-heap, and a dissatisfied customer, and the cause all to often is the salesman.

While a motor truck is in the repair-shop it is a source of double expense; indirect expense due to the overhead, because it is idle and earning nothing to meet interest charges, and because of the loss of use while it is being repaired. This latter may be a cause of serious loss and inconvenience, the exact amount depending upon circumstances and being very difficult to estimate; second, direct expense for labor and repair materials. That these two items may be kept as low as possible, the truck builder must keep two things clearly in mind. First, the design of each individual part, and the material and workmanship which go into it must be the best that can be procured, in order that the breakdowns may be as infrequent as possible. Second, the assembly and coordination of the varicus parts into the complete truck must be accomplished with the accessibility of all these parts constantly in mind. The first of these requirements will reduce the direct expense for repair labor and materials, and the second will make possible a substantial reduction in the time required fcr repairs and renewals, which will mean a saving in labor and also in overhead expense. It must be kept clearly in mind that a truck in the repair-shop is an idle truck, and anything which will shorten the period of idleness promotes economy, entirely aside from the more evident saving in the mechanics' time in making repairs.

Needed Improvements in Design

I shall now endeavor to point out specifically a few points where our experience in the operation of a large fleet of motor trucks indicates that improvements are needed. Based entirely on my experience in motor-truck maintenance, I do not hesitate to say that ignition is one of the weak points in the motor truck today. In fact, when a service call comes in from one of our trucks on the road, we invariably send out a new magneto because we find very many times that there is where the trouble lies. This does not apply, of course, in cases where the drivers know where the trouble is, but only in cases of engine trouble, the exact nature of which the driver does not know. In other words, engine troubles are due to faulty ignition more often than to any other cause. With the possible exception of poor or inadequate lubrication there is probably no condition which contributes more to

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rapid engine depreciation than faulty ignition. Carbon accumulation, dilution of crankcase oil, fouled valves and spark-plugs and general irregular and faulty performance are all chargeable to poor ignition. All these conditions increase enormously the service labor and expense required to keep the truck in operation.

I believe that designers and builders of motor trucks should give serious attention to the improvement of the magneto. In the present state of the art it is possible, I think, to build a better magneto than is being used at present on motor trucks; one that will operate for a long time with practically no attention save lubrication. It is probable, of course, that such a magneto would be more expensive than the present equipment, but intelligent users of motor trucks would be glad to pay the increased cost if assured of a better device. Operating savings, due to the elimination of the many ills which follow poor ignition, will repay them many times over for the increased cost of the better magneto. The breaker-box and platinum points give a great deal of trouble. Would it not be possible to make a dirtproof breaker-box?

There are a number of fairly good carbureters on the market, and others not so good. In my opinion, the gasoline engine has by no means reached the end of its development, particularly along the line of efficient use of fuel, which is largely a carburetion problem. When 25 to 40 per cent of all the heat in the fuel is contained in the exhaust gases, in the form of unburned or partly burned gasoline, it would appear that there is room for improvement. I believe that this improvement can be brought about to a considerable extent at least through a better control, over a wider range, of the proportions and the temperature of the fuel mixture. This control must be automatically governed by the load demands on the engine in the interest of both power and economy.

While we await the advent of more efficient carburetion equipment, the present carbureter should receive a little attention from the designer. It should be made as nearly foolproof as possible; adjustments must be few and simple, approaching automatic operation. More attention must be given to the effect of vibration on the operation of a carbureter. Leaky floats and valves often caused by vibration are wasteful of fuel and constitute a fire hazard. Furthermore, needle-valves and seats poorly designed or imperfectly made are a frequent cause of annoyance and delays.

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I believe it is the general consensus of opinion among motor-truck builders that a reliable and efficient governor is highly desirable. Because of the rapid depreciation caused by high speed, the life of engine and truck depends to a considerable extent on the efficiency of the governor. Our experience with governors is that very few of them function properly. They require almost constant attention to keep them in working order and if they are neglected the engine will soon be running wild. The average driver likes speed and cares little about truck depreciation. A governor must be simple in design and of the very best construction as to materials and workmanship. A better means than is now available for sealing the governor should be devised. It seems to me that a lock should be used, having a key which the owner or the garage superintendent can retain in his possession. This will tend to assure proper operating speeds, which are an excellent insurance against engine troubles.

Lubrication of the moving parts on the chassis is usually taken care of by the installation of grease-cups. In principle at least such a provision should be ample, but in practice the user of the truck frequently finds that the results are not satisfactory. If the filling and turning down of the cups is made a part of the driver's duties, it is almost certain that it will be neglected. I believe that fully 75 per cent of the trucks on the street are insufficiently or improperly lubricated, largely due to the fact that the driver neglects this important duty. We find from our experience that it is much better to have the greasing of the trucks done in our garage, at regular intervals, by service-men assigned to this particular duty. In this way the work is more systematically done and results are much more satisfactory. But even with this system a grease-cup will occasionally be neglected or overlooked, especially if it is located in an inaccessible position.

The design of grease-cups leaves much to be desired from the point of view of the maintenance man. They are generally cheap stampings with coarse threads. The threads are very often crossed when endeavoring to fill and replace the cups in some inaccessible place, and as a result the cup is ruined. Constant vibration frequently jars a grease-cup loose, and once it is lost it is seldom replaced. It seems to me that if a grease-cup could be developed along the lines of the self-feeding compression type, lubrication would be much more efficient and main-

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tenance expense materially reduced. If such a cup were developed, it would probably be necessary to use greater care in selecting a lubricant properly adapted to the weather and temperature conditions under which the truck operates. But this can be taken care of by the garage or service department, and need constitute no valid objection to a substantially automatic grease-cup, if one can be designed by the builders' engineers.

My experience indicates that attention should be given to the equipping of truck wheels with non-skid devices for operating in mud, snow, or ice. Many builders make no provision for any such device; others have made attempts, but I know of no successful solution of this important point. I have sent out trucks in the morning equipped with six chains on each rear wheel; at night they have come back with only one chain left. These chains are very hard on tires and springs, and impose serious strains on worm-gear drive-axles. The builder who can solve this important problem will make a valuable contribution to the motor-truck industry.

In connection with the above, I believe that some serious thought should be given to the question of cushion wheels. I am not prepared to make suggestions on this point, but believe that a good cushion wheel is much to be desired.

A motor truck is a compact, highly specialized piece of machinery, and when the final assembly is complete it is almost inevitable that some of the parts should be extremely difficult to get at. To save time in making repairs and renewals, all parts which, from their nature are most likely to need attention, must be readily accessible. Among these parts, the engine, transmission, magneto, water-pump and grease-cups may be mentioned.

The engine should be installed in such a way that it can be readily taken down for repairs. We have trucks from which the entire engine can be removed by two men in 1½ hr., and we have others which would require three times as much labor for the same job. Some engines are built so that the bottom half of the crankcase is readily removable, providing access to crankshaft and main and connecting-rod bearings with a minimum of labor. This is important, because, as every maintenance man knows, the labor of taking down an engine and reassembling it after the repairs are made, is often the largest part of the job.

The above considerations in regard to engines apply

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to transmissions also. From our experience it seems that very few builders using a transmission amidships make any provision for filling or inspecting it except through the top. If any other than a dumping body is placed on the chassis the transmission is inaccessible, and if something goes wrong the body must be removed to get at it.

As pointed out earlier in this paper the magneto is a frequent source of trouble and must be repaired or replaced. Consequently, it must be readily accessible, and also the shaft or other means of driving it. The removal of the magneto necessitates disconnecting it from the shaft, a difficult job in an inaccessible place.

Frequently the water-pump is placed in such a position that replacing becomes extremely difficult. Both the pump and the magneto may be driven from the same shaft, located where it is readily accessible from end to end. Some designs place this shaft in a transverse position in front of the engine, which in general provides greater accessibility than when it is placed in a fore-and-aft position by the side of the engine.

A grease-cup located where it cannot be reached readily is little better than no cup at all. I believe that until automatic grease-cups are devised, motor-truck builders should do everything in their power to design their machines so that the grease-cups are easy to reach, and replacing, filling and screwing down can be done with a minimum of time and labor.

Maintenance Practice

I have been asked to speak also of the care and maintenance of motor trucks. This is rather a wide subject, and I feel that I shall be telling some of you things that you already know. The Consumers Co. operates 159 motor trucks, which cover the entire city of Chicago and the outlying districts, and each day are delivering coal, ice and other supplies. Keeping these trucks on the road and cutting down expenses or making the maximum haul at a minimum cost is my job. Naturally, in the pursuance of this work, we are always on the lookout for every possible place at which we can effect a saving. It has been our experience, as I will tell you, that in no place is the expenditure of money more justified, or does it bring greater return, than in keeping our fleet *away* from repairs. I mean by this, treating all our equipment with such inspection and nightly adjustment that it is kept constantly up to a high level of mechanical efficiency. This means, to be exact, that as little time as possible is

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spent in the garage, or out of active work. I will show you how we have formed our organization to bring this about. I shall not go into details over the truck on the road, the routing, or the means by which we keep in touch with our equipment while it is moving. The modern loading and unloading devices have already shown their efficiency, so I shall not speak about them other than to mention that in our larger yards we load by overhead locomotive cranes that are capable of loading from 2 to 10 tons in 2 min. The time taken for our trucks to get into the yard, get their load and out again is usually under 5 min. As some of our trucks make us as much as $1.20 per ton, you can readily see our anxiety to keep them moving. A truck standing still earns no money.

What I do want to talk about is our garage and shop equipment. Here is the power behind the throne. This is where the trucks are kept fit. It is here that the very backbone of our system is kept nourished. Without proper maintenance, a truck cannot bring in the profit that it should. "All the trucks on the road all the time" is our motto; we try to live up to it. Here is where we differ from the modern acceptance of repairs, "the chief part of maintenance," as some put it. He is a poor doctor who will let his patient get into such a condition that the only thing which will save him is an operation. It is just as poor policy to let the first attention you give a truck ailment be a repair. Then the damage is already done and your truck will suffer forever afterward as a result; no matter what reparation you make to the injured part. It is the ounce of prevention that pays. Let me emphasize this statement strongly. Nearly all our energies are devoted to keeping the trucks from ever getting into such shape that they will need overhauling. Does it pay? It does. We have some trucks that have gone over 70,000 miles and are, as near as we can tell, in as good a condition as the day we bought them from their builder. There are some that are more than 4 years old, and show no evidence of wear. Does this speak for the wisdom of our system?

Trucks on the road are constantly under a stress and a strain. This tends to make their lives shorter than any other kind of transportation machinery. It is this depreciation that we fight. In prolonging a truck's life we reduce our cost per mile of haul with that truck. We have not effected these results without expense. Some of the items of cost have been fairly high and were some

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time in proving their value, but we are reaping the crop now. I do not think that you will consider it boasting if I say that I think we are delivering coal and ice cheaper than anyone else in the city of Chicago.

Our garages have been the subject of great care and thought. Much of our work is done at night. We have built the garages with an eye to two results; fast work and good work. Here is where these trucks are washed and inspected each night, and I might say that each truck gets this each night. Clean floors and walls of fireproof construction add to the appearance and reduce our fire risks. All inflammable gases are taken out through the wall construction. There are plenty of windows for pure air and there are few shadows. Also there are no columns to get in the way of truck or man. The floors are stripped for action. You must remember that we have over 159 trucks and each one of these has to receive an inspection, a wash and a general cleaning every night in the year. This inspection is nothing in the way of a casual "once over," but a careful looking over of each truck as it is checked in at night. By keeping our floors clean and well drained, our men are able to wash a much larger number of trucks than they would in the same time on a floor with bad drainage. Our washing and draining systems are arranged so that it is possible, in case of necessity, to wash any truck wherever it stands in the building. Our rule, however, is to have all trucks sent to the special washing floor. This floor is as free from shadows as can be. This gives the man ability to see his work so that he can get it done faster and better.

Our plumbing system is arranged for both hot and cold water. Steam boilers keep the soap and water as well as the suds at the correct temperature at all times during the washing period. This was a large expense in plumbing, but a huge saving in labor cost is the result. To avoid sewer stoppage we have large catch-basins. These are cleaned every 7 days. As tons of dust are washed out of the trucks, care is exercised to keep this from getting into these basins. The floors are cleaned with large scrapers built so that one man can handle them. This done, the floors are washed, and this is done every day. You will probably think that I am spending a long time getting my subject cleaned, but it is necessary, for now we come to the inspection. Much of the cleaning is done to bare the surface of all the truck and its mechanism so that the inspector can see if there *is*

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anything wrong. A hundredth of an inch of coal dust can cover up a multitude of troubles.

Our inspectors have good eyesight. If through laziness they become blind, they also fall heir to another position. The mechanics go over the truck every night, tightening brake-bands, straightening mud-guards and checking up on all the little things that may go wrong with the truck, and catching these flaws before they develop into serious troubles. Back of them all are the inspector and his assistant. The driver's trouble card has already eliminated any truck that has shown any minor or major trouble, and it is these trucks *apparently in good condition* that the inspector searches through to find the trouble that is brewing. That is where the ounce of prevention comes in. This inspector and his assistants cover all the trucks once every month. Not one single part being overlooked. This man has a printed form covering all parts of the truck. The inspector covers the engine in detail; the spark-plugs are adjusted and the compression of each cylinder is taken. In this way we are better able to tell when the cylinder needs regrinding. The transmission is gone over to determine the condition of the gears and if necessary filled with grease to the proper level; the clutch is carefully tested; universal-joints are Aelimate-equipped which saves much time in filling; and we never find one dry. The wheels are taken off and bearing cups and cones are cleaned and gone over carefully for worn or defective parts. Before assembling a fresh supply of grease is put into wheels, and the bearings very carefully adjusted. Since installing this system of looking after the bearings our wheel bearing trouble on the street has disappeared. All grease-cups are checked up to see if the men doing this work are doing it efficiently. The cooling system is closely checked. Rear ends and tires are checked up and their condition reported. The hoist and body are also covered. It may interest you to know that it costs as much to maintain one of these dump bodies with hoist per year as it does to maintain all the rest of the truck. This inspector's card shows also whether the engine is being kept clean, if the truck is being washed; everything must be in perfect shape or reported for repairs, so when this card is turned into the office it shows the mechanical condition and appearance of the truck. If you had a passenger car would you like it to get this treatment every month? Would it pay you?

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Now comes the slippery subject of greasing and oiling. Just as we have one man to wash from 12 to 15 trucks, we have one man whose sole aim in life is the greasing every night of from 15 to 18 trucks. That is his job and on the proper performance of his job rests to a great extent the proper performance of our trucks. I will give you an example. How many operators pay any attention to springs? Practically none that I can think of. With us this is an important item. Every spring is washed down with waste oil. As a consequence we have practically no spring trouble; and this in face of the fact that the majority of our equipment is of 7½-ton size carrying a 33-per cent overload day-in and day-out. When we take a truck down for overhauling, we invariably find the spring leaves well separated, with no rust present and lots of grease worked through. Under similar conditions, on most trucks you will find spring leaves frozen together into a solid mass of rust and metal. Such a spring lacks resiliency. This means a saving that is hidden at first thought, the saving on tires.

Handling Repairs

Sometimes, strange as it may seem, even our trucks will get out of order. In other words, they will not run. If this happens on the road, we send a service car to make the truck run or tow it in. We do not allow our trucks to "limp" in.

Minor repairs are made by mechanics capable of doing almost any kind of a job with a reasonable amount of speed and accuracy. This is done at the garage during the night. Jobs that consume several hours or more are listed for the shop. This shop is always in the hands of an experienced man. In laying out the building special attention was paid to ideal working conditions and making the men happy; good light and ventilation mean good work.

In the selection of tools and equipment, a study is made of each individual operation to find the best means of handling it. If after a careful analysis is made, it is found that tools or machinery will make a saving, these are installed. Without great care in the selection of machinery and tools it is an easy matter to fill up valuable space with machinery that will not pay the interest on the investment. Our shop equipment consists of shaping and milling machines, air hammers, drilling machines, drop hammers, special reamers for all bearings, wood-

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working machines and machines for painting. As we have been able to standardize our automobile equipment to a great extent, we are able to save in shop equipment as well as in our stock of parts. This is an example of standardization. Our machinery equipment is laid out on the floor of our shop so that repairs can be routed through in the most efficient manner, thus saving the time of rehandling and doubling back to the same men.

From our stock records we are able to know just what parts we are likely to use in our garages during the night. Having this knowledge eliminates carrying all unnecessary parts, thus saving a large sum of money and time in keeping the record of these parts. The main stockroom is connected with our shop and carries everything that goes into the truck. Our garage stockrooms draw on this one for all parts. The shop has on hand at all times an extra engine ready to go into a truck in case one comes in with trouble that would necessitate taking the engine out. The extra engine is put into the truck while the one taken out is repaired and put into stock prepared for a similar case. This liberates an investment of some $8,000 to keep on with its work of earning money for us. We have extra electric motors and batteries for the electric trucks, extra wheels for both gasoline and electric trucks and complete steering posts; in fact any unit that our experience has taught us will save time and keep our trucks moving at all times. Our stockroom is arranged for keeping a perpetual inventory. There is no kind of job on a truck that cannot be handled in this shop.

All our men are most carefully selected. We treat them well and they know it. There is always a waiting list of applicants; by having a quantity to pick from we get a good type of man. There are factors in human nature that work against efficient organization and there are those that work strongly for it. Pride and contentment are our aids; and these we try to build up in our own men.

Perhaps what I have said today has not been sufficiently specific. It may be that I have attempted to cover too much ground. I hope not. It is quite possible that some of you will think that we have built up too big an overhead for our equipment. I can only assure you that I have given you the honest result of our experiments and experience. It is more economical to spend money in the prevention of trouble than it is to let the oppor-

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tunities for saving slide by, gamble against the law of averages, and then, in the end, pay the same amount of money and more to repair defects.

THE DISCUSSION

GEORGE T. BRIGGS:—I ask the following questions:

(1) How much mileage do you obtain from a set of final-drive chains, and what is the total maintenance cost during the period of that mileage?
(2) How often do you find it necessary to regrind cylinders and fit over-sized pistons?
(3) How often do you take up connecting-rod big-end bearings?
(4) How often do you regrind crankshafts?
(5) How often do you replace the friction disc of the clutch?

N. J. SMITH:—We get about 10,000 miles from a set of chains, depending upon the nature of the work; in hauling coal alone, we have run as high as 15,000 miles; if we are hauling stone or sand, the chains will not last as long.

The care that is given the engine determines the frequency of regrinding cylinders. We have engines in operation which have run over 30,000 miles without the cylinders being reground. Other cylinders have been reground after 15,000 miles. With good lubrication the engines will run years without regrinding the cylinders; lubrication is the big item.

The taking-up of connecting-rod bearings is another thing that is governed to a great extent by the care given the engine, although there are many things that have an influence on that. I would only be guessing at an average, as I did not come prepared with those figures. We have often run engines for 2 years without taking up the connecting-rod bearings; some have run longer than that.

I cannot say when it is necessary to regrind crankshafts. We have trucks more than 4 years old on which the crankshafts have not been reground. We found less than 0.002-in. wear on those shafts. That probably seems like an extreme statement. Lubrication is a main item there, also.

As to how often we find it necessary to replace the friction disc of the clutch, I have had trucks on which the clutch has burnt out within a month's time; other clutches have run years without repair. Unless a driver has an accident or gets stuck and burns a clutch up, we can say

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that it will last 1½ to 2 years; sometimes longer than that.

A. L. NELSON:—What kind of records are kept on fuel oil economy?

MR. SMITH:—We have a man who studies the amount of fuel and oil used. He spends all his time following the trucks on the street and in the garages. We are paying more attention to this subject than ever before. We are improving our fuel consumption.

F. J. SULLIVAN:—How many miles does one of these trucks make in a month?

MR. SMITH:—We estimate 1000 miles per month.

W. S. NATHAN:—Has Mr. Smith installed any apparatus to reclaim the crankcase oil? What does he do with the oil if he does not reclaim it?

MR. SMITH:—We have a filter in our main garage that we put the oil through. We take out all the dirt and grit and use the oil in our hoists. I have tried reclaimed oil in the crankcase recently, but only experimentally.

W. J. GRAMM:—I believe Mr. Smith mentioned that he included a 33⅓-per cent overload. Is it customary for the company to include that percentage of overload?

MR. SMITH:—Yes.

MR. GRAMM:—Is it possible to do that and maintain the trucks properly without serious trouble?

MR. SMITH:—I can give no statistics for or against it. We are doing it and believe we are successful. We cannot see wherein a truck is not keeping up to its standard as well with a 33⅓-per cent overload. We are watching the speed. We know that speed is more dangerous to the truck than overload. Speed is one thing that we keep away from.

H. M. RUGG:—How large a force of mechanics does Mr. Smith keep at work in the repair-shop? What methods are used to train or instruct them in the work?

MR. SMITH:—Our mechanical force is small and consists usually of men we take on and instruct. We teach them the business.

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TRACTOR SERVICE REQUIREMENTS

By J C Thorpe[1]

The paper treats of the service, commercial and technical aspects of the subject in turn. The author calls attention to the fact that there can be no such thing as free service, because the customer pays in the end, and gives a specific definition of service. He argues that the engineering departments should urge upon merchandising departments intelligent distribution through dealers, the stocking of an adequate supply of parts and the maintaining of a well qualified mechanical force for the purpose of making engineering development work in the form of farm power automotive apparatus effective.

There is a great need for a suitable system of training mechanics for tractor service work, and there should be a definite plan to assure that men making repairs and adjustments in the field are well qualified.

In conclusion, the author pleads for continued consideration of the subject of accessibility of parts in tractor design, the use of better materials, reduction of weight and the furtherance of a program to increase the number of tools driven by tractors in farm work.

It requires no little amount of courage to appear before a group of engineers who are so familiar with the technical details of the farm tractor and attempt to present anything on the subject of service. Volumes have been written on the subject and there is scarcely a dealers' or engineers' association program on which it does not have a prominent part. The only reason for a repetition of discussion lies in the fact that we seem to be about as far from reaching our objective as we were several years ago. It is entirely probable that if we were to take a vote of this meeting, it would be very difficult to secure the opinions of any considerable number that might approve a definition of what we call "service." You will understand, therefore, that I do not have in mind the presentation of any new facts. It may be possible to dress up some of our present arguments in a little bit different attire so that their importance will be more strongly emphasized upon our mind. It is my purpose to present the subject in three phases: (*a*) general consideration, (*b*) the commercial aspect, and (*c*) the technical aspect.

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[1] Barnett & Wilson Investment Co., St. Louis.

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General Considerations

One subject is very closely related to a question that has been very much discussed in the trade press and upon the floors of dealers' conventions during the past 3 or 4 years. This refers to, "Who is the logical tractor dealer?" Two groups have been involved in these discussions and have taken positions almost immeasurably apart. The old-time implement dealer says that he is the logical tractor dealer because he has been selling to the farm trade for years. He knows the farmer and his problems; also his habits of buying and selling. He is sure that irrespective of other considerations his own farm trade will buy tractors from him and from no one else. He states, with emphasis, that no other merchant should encroach upon his territory and that the tractor factories should give him precedence over all others. The automobile dealer claims that he is the logical one to merchandise tractors because this equipment has very definite service requirements and he is thoroughly educated in taking care of the needs of those in his community who use automotive equipment. In my opinion all of this discussion has been misdirected and has failed entirely to reach the point. The dealers mentioned have failed to recognize the essential qualifications of a merchant in any mercantile community, namely, the ability to merchandise good goods at fair prices properly and having consummated sales to occupy the position of a consulting expert in relation to the customer.

It is not important that the old-time implement dealer is familiar with the farmer and his problems, nor that the automobile dealer has been trained in the art of giving service, when considering the substantial qualifications of a real merchant. Whoever of these groups measures his right to sell by the standard I have indicated to be the proper one is the logical tractor dealer. Because of the universal appeal of the farm tractor to the farming interests of the country, the sale of farm tractors offers opportunities for the development of "good-will" that are unequalled by any other merchandising activity. This very tangible asset is the essential cornerstone upon which the structure of every successful enterprise is built. It is always evident in thoroughly businesslike and fair dealings between the buyer and the seller and becomes intensified in the development of subsequent satisfactory business relations. The manufacturer, by producing an article of merit, honest

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advertising and a long period of fair treatment of the dealers, cooperating with them in promoting the interests of the customer, gradually attracts to himself and to his product a certain amount of public interest and approval. This degree of public approval is the measure of the manufacturers' good-will account. It is developed only by careful, honest and persistent effort through a period of years, but it may be destroyed by one false step.

We often hear, "What's in a name?" In my opinion that dealer who does not continually strive to make his name mean something in his community that will add to the economic wealth is missing what might be termed his logical objective and his right to permanency in his community may readily be questioned. Marshall Field has become a name to conjure with in the homes of this country, because of an attitude toward the customer based upon the conclusion that "the customer is always right." You are brought face to face upon the streets of St. Louis with the slogan "Don't say paper, say Star." My conclusion is that a tractor dealer should so persistently pursue the highest type of merchandising methods that his name will be inseparably identified in the mind of his market with the farm tractor. This result may be anticipated if the dealer outlines and carefully carries out a program that creates an impression of his thorough understanding of the subject and the adequacy of his service organization. Fundamentally, this conclusion is based upon the principle that tractor service meets an economic need; and to him who satisfies this need will come the reward of an enlarged and increasingly profitable business.

Cooperation between the dealer and the manufacturer is necessary in carrying out this program. The manufacturer is not a very tangible factor in the investment, judged from the standpoint of the purchaser, who seldom, if ever, comes in contact with the factory organization. And, while the manufacturer is dependent upon the good-will of the trade, as stated before, he must arouse public interest and approval through his intermediate trade factor, the dealer or distributor. This involves the maintenance of an adequate stock of repair parts, an efficient service and inspection department and an attitude of favorable forbearance with respect to service claims. It is the dealer to whom the customer looks for relief when equipment fails to measure up to his expectations, either in performance or in the quality

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of materials or workmanship. It is this mental attitude on the part of the buyer that often places the purchase upon the basis of a selection of the dealer rather than upon a selection of the specific item of equipment or merchandise. It is thus that the ability to "keep goods sold" becomes of equal importance with the art of selling, and presents a problem in which both manufacturer and dealer are vitally interested.

The Commercial Aspect

"Service" has become the pet slogan, expressed or implied, of nearly every business organization. It has been rolled like a choice morsel under the tongue of factory managers, accessory and supply jobbers, implement dealers, garage operators, crossroad repair shops and salesmen alike. It is to be regretted that claims to service superiority have not always been supported by a service plan tended to justify them. Despite the apparent familiarity with this magic word, it can be stated with assurance that it has almost challenged definition. I seriously question whether any considerable number of us here would spontaneously approve any definition that one of us might present. In the mind of the automobile owner it has meant anything from a "cursory once-over" accompanied by a copious discharge of so-called expert advice, to a semi-annual overhauling during the life of the car, without expense to the owner. Quite innocently, the term "service," whatever it may be understood or misunderstood to be, has become the vehicle of the most pronounced fallacy in the merchandising of machinery, damaging to manufacturer, dealer and customer; namely, the possibility of getting something for nothing. "Service" has been paraded in most alluring dress before the mind of the prospective purchaser by the unscrupulous salesman to the extent of creating an expectation of expenseless ownership. The rude awakening of the owner discredits the salesman, the dealer, the manufacturer and the product. There can be no such thing as free service. Such a conception is opposed to the economic law of compensation. To give service requires time and money, labor and materials, and for these someone must pay. In the end it is the consumer, because in the chain of trading events all the money must come from him.

The success of every merchandising enterprise is largely dependent upon the interpretation of this word

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service. Satisfying service for reasonable compensation always develops good-will between the seller and buyer. It goes far toward making the enterprise impregnable to the assault of depressing business conditions. If an article has merit, if it meets an economic need, somewhere there is someone with the inclination and the ability to buy, if he has the opportunity. Business depression may diminish volume and greatly increase selling costs and thus reduce profits but it does not completely destroy selling opportunities. A reputation for honest manufacturing, for courteous and courageous salesmanship and for rendering satisfying service can be expected to bring its reward in maintaining an open channel of trade when times are "hard," and a continually increasing volume of trade, the goal of every ambitious enterprise, in periods of normalcy. The bugbear free service often introduces factors of abuse and unfairness in competition. Sales are often made, apparently, upon the basis of "who can give the most away." After the gross profit disappears in the negotiations, "free service" enters to bait the unsuspecting prospect further. It destroys confidence, separates business associates, debauches business character and attacks industrial progress. It makes impossible that close cooperation among dealers that is most healthful for trade development. It cheapens the product of the manufacturer and reflects discredit upon his selling organization. The term service, properly understood, thus loses its identity with the appearance of unfair trade tactics. If the purchaser, either through a misunderstanding of the service obligations of the dealer or by forethought, asks for and receives concessions incompatible with good business procedure, a fictitious value is placed upon the goods sold. Such a value cannot be maintained and thus another phase of price-cutting is introduced that is ruinous, not only to the individual dealer but to the industry. It would appear that the following definition may be a proper one:

> *Service*, as applied to the operation and maintenance of power-farming machinery, is the cooperation of the dealer with the owner, whether he be the original purchaser or not, during the life of the equipment in the dealer's district, to the end that the owner may secure continuous use of his investment at the lowest reasonable cost

We all recognize that service is arousing the same general discussions in assemblies of representatives of

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the tractor interests that have been prevalent for years in the automobile industry. Unless the present agitation is curbed and thought directed by the leaders in the power-farming-equipment field along the lines of reason and good sense, it is probable that we shall experience the same difficulties and pass through the same period of chaos that has characterized the development of the motor-car.

Some confusion frequently arises in the interpretation of the factory warranty covering parts that fail due to faulty workmanship or material. Today, this warranty is limited to the replacement of such parts after they have been shipped to the factory, charges prepaid, inspected by the factory inspection department and found to come under such warranty. Repair parts are then shipped to the dealer or owner as the case may be, f.o.b. the factory shipping point. There are occasional departures from the factory policy of paying no labor charges. A clear and positive understanding of this warranty between the factory and the dealer, and through the latter, with the customer, is essential for the purpose of eliminating discussions with owners that often become embarrassing to all parties concerned and damaging to business.

Many factories maintain a corps of skilled mechanics who cover the territory to extend mechanical service to dealers with incompetent or no service-men or to isolated owners who cannot appeal to the local dealers for service. The maintenance of this group of mechanics involves a material expense for which the manufacturer must be compensated. In most instances contracts do not differentiate between the dealers with adequate service facilities and those without. It is clear that this policy places a premium upon inadequate service and offers no encouragement to the improvement or development of service facilities.

It is a serious question whether we are near enough right in the present status of the factory warranty to begin the consideration of improved service with the conditions existing in the dealer body. My opinion is that a system of merchandising must be developed whereby a premium is placed upon adequate dealer service. This can be expected to place an ideal before the careless merchant that should prove an inspiration to attain to a higher plane of service activity. It should

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go far in attracting into the industry men of real commercial ability and achievement.

There are certain principles of design that appeal to the sales engineer, along the lines of which you are undoubtedly directing your energies. A tractor should possess such ease of control and operation as to make the employment of skilled labor on the farm unnecessary. I have frequently run across farmers who have persistently refused to consider the purchase of a tractor because they felt there was no one on the place to run it. The tractor should be of such pronounced simplicity and accessibility of mechanical detail as to guarantee a minimum loss of time and money for needed repairs, replacements or adjustments. It should have proved economy of operation and maintenance in order that it can make an appeal to the purchaser from the angle of an investment. The designer should have constantly in mind the fitness of the machine for the work it is proposed it shall do. It is to be regretted that this particular quality has been too much neglected in the tractor field with respect to design and to the selling policy of the factory and the dealer. I am convinced that much of the unfavorable criticism of the tractor has come from the fact that the purchaser was sold equipment that was unsuitable for his requirements.

I have been astonished at the lack of attention to what I consider a most important detail, the comfort of the operator. Salesmen talk loud and long about the merit of power-farming equipment as it relates to independence of weather and labor conditions. The farmer may await the arrival of settled weather before he begins his work and then by working 20 to 24 hr. a day catch up with his neighbor who is utilizing antiquated horsepower. The fact that he is to sit in a cramped position from sun-up to sun-down under the direct rays of a broiling sun upon a malleable-iron seat upholstered in black enamel is never mentioned. No arnica or liniment is sold with the tractor and yet this is about as necessary an accessory to the machine as oil or water.

Frequent and expensive interruptions in service are occasioned by delay in securing repair parts. However careful the dealer may be to maintain his parts stock, occasions will arise when he must appeal to the factory for assistance. Frequently this assistance is not given promptly because no parts are available from the factory stock. This presents a production problem that must have attention if power farming is to receive the ap-

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proval it warrants. It would seem that the great desire for the production of completed units has obscured the question of what shall be done for them after they are sold and put to work. A proper scheduling and control of parts production should eliminate this difficulty. Too little attention is given the dealer in the selection of his parts stock. The industry is too young and the experience of the dealers too limited to expect the exercise of accurate judgment respecting parts requirements. It is highly desirable that this problem be given careful consideration by the engineering departments, in the preparation of parts lists based upon actual field experience, which can be placed in the hands of the dealers when executing their contracts.

Some of the most conspicuous successes in the industrial development of our country have been based upon the development of a training school within the enterprise. I have in mind the many special apprenticeship courses that are available for those requiring special training within either the parent organization or its external connections. Service will not be organized upon the most desirable plane until men are available who will take their places as skilled mechanics in the great dealer organization. Some hit-and-miss plans of training tractor mechanics are in operation in several factories at this time. The manufacturer of power-farming equipment who gets a real vision of this problem and outlines a definite program of specialized training for tractor mechanics or service men, will secure a wonderful asset. The organization of service schools by the tractor companies shows an appreciation of the problems in operation and maintenance that confront the tractor operator. The principle is right, the motive commendable, but the method wrong in most instances, in my opinion. Too little attention is given to differentiating between field operations and service-station or shop operations. It is not wise, except in rare instances, to encourage the farmer to undertake service-station operations with the inadequate shop facilities existing on the average farm. And yet it seems that most of the instructors in charge of the mechanical-service schools place the greatest emphasis on taking magnetos apart, charging the magnets and reassembling the unit, taking down the crankcase and refitting bearings, etc., giving entirely too little attention to emergency field operations and ordinary inspection.

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Most of the problems presented would respond to a closer cooperation between the sales and the engineering departments. This should develop a greater sympathy between the departments relating to the difficulties that are of mutual interest. Greater interest of the engineer in field activities would go far toward a solution of mechanical service as it relates to the design, and a keener interest in the problems of the engineer on the part of the sales department would unquestionably enhance the effectiveness of the selling campaign.

I can think of no development that would be of more permanent and immediate benefit to this great industry than the organization in every factory of a merchandising and engineering research department that would link up and conserve the energies of selling and production. In its relation to service, this department would be of incalculable value to the dealer, and if to the dealer, to the American farmer who yet needs to be "sold and kept sold" on the power-farming idea.

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FARM-POWER MEETING AND DINNER

The Sixth Annual Farm-Power Meeting of the Society, held at Columbus, Ohio, on Feb. 10, during the week of the National Tractor Show, resulted in the presentation of much information of technical and economic value. More than 200 members and guests attended the professional sessions and the dinner.

Plowing Speeds

E. A. Johnston, the vice-president of the Society representing tractor engineering, presided at the technical sessions. D. L. Arnold, chairman of the Society committee that has been making an exhaustive study of plowing speeds reported on its current work. He made it clear that less power is required to plow with three bottoms than with two bottoms at the higher speed necessary to cover the same acreage in a given time; furthermore that at the same speed the cost of the three-bottom plowing is less. The power required increases with the speed, apparently regardless of the type of soil, that is, in about the same proportion in sand, stubble or 7-year old sod. The cost becomes less as the speed increases, and about proportionally with all soils. Mr. Arnold feels that while certain fundamental facts with regard to plowing speeds have been determined definitely, much further research is necessary in connection with them. He advocates the use of the term "rate of plowing" or "plowing velocity" in expressing plowing speed, inasmuch as with changing conditions high speed of today may be considered low speed tomorrow. Professor Davidson, of Iowa State College, confirmed the general deductions made by Mr. Arnold, stating that the variation in the depth of plowing has more influence than speed on the amount of power required. He said that about 14 factors are involved in determining the draft of a plow, the principal increase in draft being due to the effort necessary to turn the furrow slice. He expressed the opinion that the shape of the moldboard does not affect the draft and that there is an opportunity to change the design of plows so that they will have less surface in contact with the soil.

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Chairman Johnston said that the draft of a 14-in. plow varies from 200 to 1800 lb., and that, as there is no one best plowing speed for all conditions, it will be necessary to standardize on perhaps three different speeds. Major O. B. Zimmerman said that the committee's experiments are of vital importance as it is essential to secure economic gain, however slight this may be, by the institution of scientific methods in farm-power operations. Every detail should be gone into carefully with a view to attaining the best possible results with a tractor having an assumed life of 7 years. Granting that the cost of the tests being made will amount to $50,000, the work will nevertheless result in a net saving in comparison with determining the right plowing speeds by empirical methods.

Anti-Freezing Solutions

The subject of anti-freezing solutions, which is of yearly recurring interest, is of such importance in the tractor field that a special committee of the Society was established for the purpose of making a thorough study of the use of certain mineral oils and of mixtures of salts or fluid chemicals with water to lower the freezing point of the mixture, with a view to making specific recommendations of constructive value in the operation of tractors. Major Zimmerman, who is chairman of this committee, made a progress report at the Columbus meeting. He said that it may be necessary for the committee to undertake research in a way analogous to that followed in the case of lubricants and fuels. Disregarding the mineral oils, the cooling medium should be cheap and easily obtainable, non-corrosive, not cause electrolytic action, have a boiling point not too high above that of water, not freeze much above — 20 deg. fahr., have low viscosity, be a minimum fire hazard, have high thermal conductivity and possess other characteristics which Major Zimmerman enumerated. Concerning the use of salts like calcium chloride, it is stated that the hope that the average user would make his own solution is futile. The committee feels that the use of salts for preventing freezing is undesirable in view of the almost certain electrolytic action involved therein. The free boiling off of alcohol means uncertainty as to the nature of the solution in the engine. However, a mixture of 1 part amyl alcohol to 39 parts of water freezes at 31.1 deg. fahr., and unlike ethyl and methyl alcohol has a boiling point of 264 deg. fahr. Its

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intoxicating effect far exceeds that of ethyl alcohol. With regard to the group of mineral oils, the committee feels that the arguments against these for use as anti-freeze fluid are based in large part on lack of accurate information. Tractors have been cooled successfully for many years with heavy oils during all seasons. The committee will endeavor to secure complete technical data on the characteristics of the mineral oils in question.

John A. Secor, pioneer engineer of the Advance-Rumely Co., said that his company had used oil for cooling for 12 years and equipped 30,000 tractors with oil-cooling means adapted to all climates and atmospheric temperatures. The packing in the pump gland requires replacement usually about once each season. The cooling oil is circulated by a centrifugal pump driven from the engine camshaft. Ordinary commercial Winter Black oil is used. The oil should be non-freezing and have an initial boiling point of not less than 500 deg. fahr. Radiators designed for water cooling are not ordinarily suitable for oil cooling. The general characteristics of Winter Black are as follows:

Pour Test, deg. fahr.	20
Viscosity at 104 deg. fahr., sec.	181
Viscosity at 210 deg. fahr., sec.	46½
Flash Point, deg. fahr.	345
Fire Point, deg. fahr.	385
Range of Boiling Points, deg. fahr.	550 to 750

On account of the viscosity of the oil at freezing temperature, it is customary to add kerosene to the Winter Black in the winter for adequate pumping action. As warm weather approaches, the kerosene evaporates gradually. The average temperature of the cooling oil as discharged from the cylinder jackets is from 175 to 200 deg. fahr. Winter Black does not deposit tarry material at its working temperatures. Mr. Secor made it plain that only suitable oil of known characteristics should be used for cooling. Engine lubricating oil is not suitable.

Dr. D. R. Harper gave an outline of the research work on radiators that has been done at the Bureau of Standards. He said that while the scientific work that has been done here and abroad provides much information, there are few data suitable for use in preparing specifications for radiators for automobiles and tractors, although under known conditions some of the results obtained in testing aircraft radiators are applicable. The heat transfer varies as the 0.8 power of the air-flow, the flow of air through the radiator being less than the velocity of the

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radiator through the air. It is necessary to know the actual rate of air-flow through the radiator core. The matter of the course of travel of air after it passes through the radiator has received too little attention. The specific heat of the cooling medium is of course important, but its thermal conductivity is so great that there is practically no difference in the temperature of the liquid and of the metal with which it is in contact. The Bureau of Standards has done only preliminary work in the study of anti-freeze solutions. Dr. Harper said that ordinary ethyl alcohol has a corrosive effect on copper and brass.

Nebraska Tractor Tests

Prof. Oscar W. Sjogren gave an exposition of the tractor tests conducted and the equipment used in furtherance of the provisions of the law of the State of Nebraska regarding the sale of tractors there.

Carburetion of Alcohol

A. W. Scarratt made a valuable contribution in the form of a report on intensive experimental work done recently by the Minneapolis Steel & Machinery Co., with which he is associated, in developing an engine to burn alcohol economically and efficiently.

Trend of Tractor Design

Mr. Johnston gave some very illuminating information by showing some moving pictures of an experimental two-plow tractor designed for use with many kinds of farm operating equipment, the various implements being readily attachable and detachable without the use of tools of any kind, such as hand socket-wrenches. It appeared that the development which Mr. Johnston demonstrated was a revelation of tremendous importance to the tractor industry, agriculture and the Nation. The essential feature of the apparatus is the transmission of the power directly from the engine to the implement, eliminating the transmission of power through a ground wheel. This, Mr. Johnston said, causes less trouble in operation and has other advantages.

Dinner Addresses

Professor Davidson presented the view, contrary to those ordinarily expressed, that there are now a sufficient number of men resident on farms in this country, and

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that the main things to be borne in mind are increasing the production efficiency per man and the comforts, conveniences and attractions on farms. There are 8000 less farms in Iowa than there were 10 years ago. In India 90 per cent of the population live on farms. But this is not evidence of a healthy condition, the standard of agriculture there being of course low.

Mr. Taber, master of the Ohio State Grange, said that the automotive engineers can do more for civilization than any other body of men of equal number in this Country. The progress in agriculture that has been attained is the result of the work of the automotive engineer. Manufacturing genius developed America. Power generation and farm machinery are inextricably interwoven.

W. H. Stackhouse, president of the National Implement and Vehicle Association, whose members produce 93 per cent of the farm-implement output of this Country, addressed the members on the immediate problems of the farm operating equipment industry.

Mr. Stackhouse quoted the Federal Trade Commission report to the effect that during the period from 1913 to 1918 the average price of farm implements increased 72 per cent. In this time all other commodities supplied to the farmer increased in price 97 per cent, and the farm products themselves 118 per cent. Considering the years 1913 to 1920, the increases were as follows: farm implements, 78 per cent; farm products, 112 per cent; labor, 115 per cent; other commodities, 144 per cent.

Mr. Stackhouse paid a splendid tribute to standardization and its value in intelligent selective elimination of unnecessary sizes and immaterial differences in elements involved in manufacture. He said that work of this nature had saved the American farmer $10,000,000 last year. The Federal Trade Commission has reported that 22,000 different types of farm implement were being produced.

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FARM-POWER DINNER

The Farm-Power Meeting held at Columbus, Ohio, Feb. 10, 1921, terminated with a dinner attended by more than 200 members and guests, which was a satisfactory conclusion to this instructive session, especially with regard to the high character of thought expressed by the speakers. After appropriate remarks, President Beecroft introduced Fred Glover as toastmaster for the evening. Prof. J. B. Davidson, of Iowa State College, who has been identified prominently with the American Society of Agricultural Engineers, had as a subject The Engineer's Interest in Agriculture. L. J. Taber, master of the Ohio State Grange, delivered an address on The Rural Situation. President W. H. Stackhouse of the National Implement & Vehicle Association, spoke on the General Conditions of the Times.

PROF J B DAVIDSON

We have many persons who would solve the farmer's problem for him. Some suggest that the primary interest of agriculture is the maintenance of soil fertility. If this were true, we would find the highest state of agriculture in Korea, for instance, where they have maintained agriculture for 40 centuries; but the Koreans have grown larger crops from the land in the past than they do now and it cannot be true, for there we find almost the lowest standard of agriculture that can be found anywhere in the world. Again, there are those who insist that the primary essential to the progress of agriculture is the production of maximum crops from a unit area. If that were true, we would find on the European Continent the highest standard of agriculture, because Europeans produce more from an acre there than we do; yet we find there a low state of agriculture, indicated by the presence of peasantry. Some suggest that we are unfortunate because the rural population of the country is decreasing. The recent census shows that we have fewer farms in Iowa, one of the States which always stands near the lead in agricultural production, than we had 10 years ago. I assert that the percentage of rural population does not make for a high standard of agriculture because, if that were true, we would find the highest standard of agricul-

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ture in India, where 90 per cent of the people live on farms. With the 10-acre dry farm and the 5-acre irrigated farm a very low standard of agriculture is revealed by the standard of living. In California, where they undertook to put the Little Lander idea into effect, people settled on 2 acres or so and were not able to produce enough to afford them railroad-fare to get away. We do not need more people on the farms.

There are others who say that our farm land is running out. We have never had a shortage of food in the United States. The trouble now is that we have a surplus we cannot dispose of. The only time there was a shortage was when the Indians inhabited America; then, at times, there was famine. Last year I talked to a young Chinaman who informed me about the famine conditions in China. I attributed this to a lack of land, but he said that China has millions of acres of virgin land that have yet to be cultivated. This surprised me. I align myself with the new school of economics which insists that what we want is efficient agriculture. In using the word efficient, I refer, in part, to the social structure. The trend of our country depends upon the status of rural life. The health of the people on the farm is a factor. If they are to be efficient, they must be physically sound and strong.

Does capacity for production make for efficient agriculture? Regardless of the other factors, which are important, if we are to have a high standard of agriculture we must have a high capacity for production on the part of the individual. It must be possible for the individual farmer to produce a surplus. Most of the operations carried out on the farm are mechanical in nature. In growing a crop of wheat the operations of preparing the seed bed, planting the seed, harvesting the crop and transporting it to market, are all mechanical processes to which engineering principles and mechanical methods can be applied. The application of power has had a wonderful influence on production. It is possible now for a man to produce 30 times as much small grain today as he was able to produce in 1830. Along with the changes in production ability have come changes in wages and in the mental and physical conditions which surround the farm. We have passed through a development from hand to horsepower methods of farming and motor-tractor farming is here. It is now common to point out the enormous amount of power produced for agriculture by horses, tractors, steam engines and windmills. The aggregate

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is 25,000,000 to 30,000,000 hp., more than is used in all the manufacturing industries together. This is an inviting field for the engineer. It has been pointed out what an enormous sum would result in 1 yr. if we could effect a saving of 6 per cent in the plowing cost. Few engineers are studying as carefully as they should the economy that might be brought about in connection with the application of power to agriculture.

I take issue with the man who insists that there is no engineering in agriculture. It is one of the largest fields for the engineer. There is a great future ahead. I expect to see the day of larger tools, when a man can do even more than he is doing now on the farm. I expect we will have tractors that will go through the entire cycle of intertilled crop production, which is a great problem now. We will have cultivating mechanisms driven direct by the engine instead of having drag mechanisms going between the rows. We will have revolving cutters that will not only make it impossible for a weed to remain but reduce the soil to a good condition of till and provide a mulch. Perhaps we will synchronize machines and cultivate in between the hills. We will have the automatic plow and automatic combination implements. We will have the truck with the corn-husking attachment on the side.

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FARM-POWER MEETING PAPERS

THE CARBURETION OF ALCOHOL

By A W Scarratt[1]

The author describes the development of an alcohol-burning tractor engine, after having stated a few of the fundamental requirements for burning alcohol economically and the results that can be attained by following them. The first trials were with 127-lb. gage compression at a normal operating speed. The problems attacked were those of what amount of heat applied to the mixture is desirable and its general effect on economy, output and operation; power output; general operation of the engine; and fuel consumption. The experimental work was done on a 4¼ x 6-in. four-cylinder 16-valve engine; this is described in detail and the results are presented in chart form. The conditions necessary for the proper use of alcohol as a fuel are discussed.

We are all very familiar with the demands of the automotive industry upon the petroleum resources of this Country, and also the rest of the world, and we know the effect which this demand has had upon the characteristics of the fuels commonly used in automotive work. The continued rise and spread of the range of temperatures required to vaporize these fuels have caused engineers, manufacturers and the public an untold amount of worry, grief and expense, not only from the standpoints of design, production, cost and operation, but in connection with increased fuel and lubricating-oil consumption and increased repair bills of all kinds that can be traced back to the fuel problem. But the greatest effect which this abnormal demand has created is reflected in the price per gallon of gasoline which in the United States has quadrupled in the past 10 years.

The ever-increasing demand for cars, trucks and tractors in this country has been accompanied by a continual advance of the power-farming idea in foreign countries, with a resultant foreign demand for American farm-power equipment. Several of the larger tractor-

[1]M. S. A. E.—Automotive engineer, Minneapolis Steel & Machinery Co., Minneapolis.

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building companies are enjoying a healthy and continually increasing export business, which can be cultivated and brought up to almost unlimited proportions provided the builder will produce tractors of proper design and construction to meet the farming conditions and operating requirements as they prevail, and at a price which makes it possible for the foreign customer to buy. In general, the size and construction of the first-class American tractors are satisfactory. The greatest obstacle confronting most of them is the use of foreign fuels in an economical and satisfactory manner. Cuba, Brazil, Argentina, Chile, Porto Rico and Venezuela are fertile fields for the American tractor and lie at our door, so to speak, but in these countries petroleum fuels are very expensive; while, on the other hand, alcohol, which is produced in vast quantities, is very cheap by comparison. Naturally, if American tractors are to succeed in these countries they must be equipped to operate on alcohol in an economical and efficient manner. Many manufacturers claim that their engines will operate on alcohol, and they will, but in a very inefficient and wasteful manner because they are not primarily designed with a view to using alcohol as a fuel.

Developing an Alcohol Tractor Engine

We have notions as to what should be done to an engine in order that it will operate on alcohol but few of us have had to put our ideas to work and prove them in the dynamometer room and in the field. The Minneapolis Steel & Machinery Co. has exported a large number of tractors in the past 12 years, during which time many of them have been required to operate on alcohol. But it is only in the last two years that the demand for greater economy and efficiency when using alcohol has been seriously felt. During 1920 we conducted some intensive studies and experimental work in the development of an engine that will burn alcohol economically and efficiently and I shall endeavor to acquaint you with a few of the fundamental requirements and with the results to be attained by their use.

Alcohol is difficult to vaporize, and hence difficult to start on. It ignites at a considerably higher temperature than gasoline, is only six-tenths as rich in heat units as gasoline by weight and 15 to 20 per cent heavier by volume. Commercial alcohol contains approximately 10 per cent of water by weight and from 10,000 to 12,000 B.t.u. per lb. Its specific gravity is from 0.80 to 0.84 at

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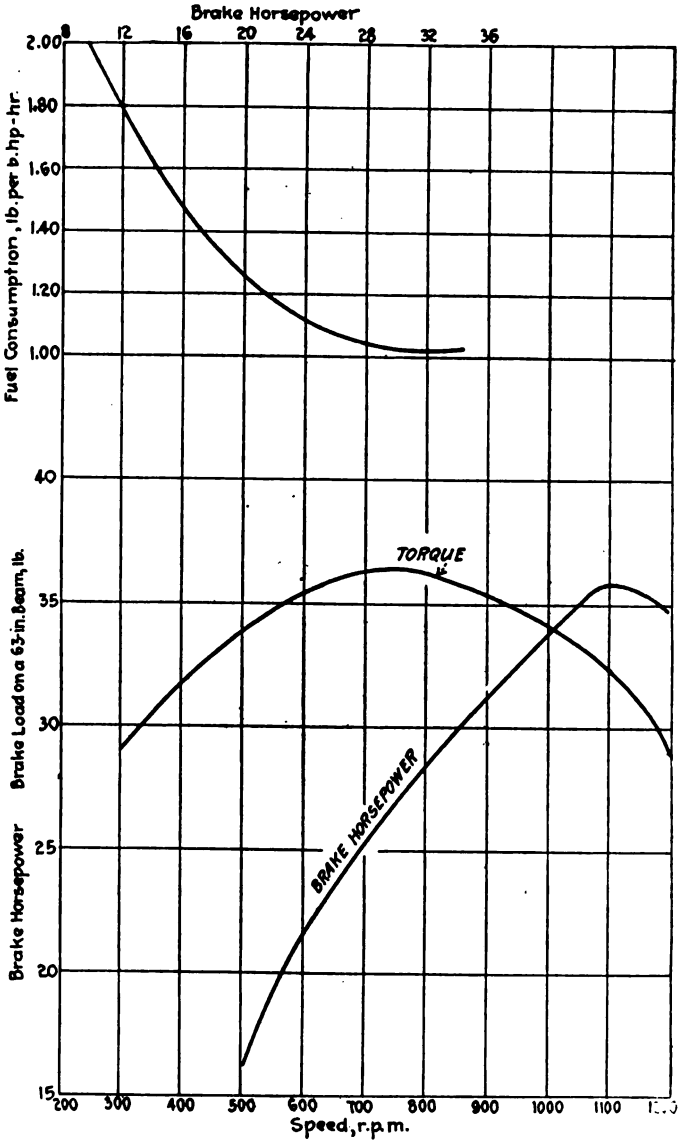

FIG. 1—CHARACTERISTIC CURVES OF A FOUR-CYLINDER ENGINE EQUIPPED WITH A SPECIAL HOT-SPOT MANIFOLD FOR BURNING ALCOHOL

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60 deg. fahr.; its range of distillation temperatures is from 158 to 175 deg. fahr. It is a vegetable derivative. These physical characteristics are of course materially different from those of the common petroleum fuels.

We knew that higher compression was necessary, but, as engine size and design influence operation to a large extent, our first problem was to establish an approximately satisfactory compression pressure from which to start our experiments.

Our first trials were with 127-lb. gage compression at a normal operating speed.

The next problem was to determine what amount of heat applied to the mixture is desirable and its general effect on economy, output and operation. We had a real surprise when we found that more heat is needed for good operation on alcohol than is required for using kerosene.

Our next concern was with the power output. This we found was equal to the power developed when using good kerosene. We then devoted ourselves to the general operation of the engine and finally the fuel consumption. At first the operation was not good at low engine speeds under sustained load and the fuel consumption was higher than we liked, but by perseverance and patience we overcame these obstacles and produced very reputable characteristics with good economy and excellent operation, using two distinct and totally different types of carbureting and manifold systems; one of which was the special Twin City Holley system worked out by our company and employed on all Twin City tractors at the present time and the other the Twin City vaporizer system which I described briefly at Ottawa Beach last summer.

As stated before, the heat value of alcohol is only 60 per cent of that of gasoline, it contains 10 per cent of water by weight, it is difficult to vaporize and requires a higher compression pressure which results in increased mechanical friction in the engine. We therefore felt that if we could obtain the same power with alcohol as with gasoline or kerosene for the same expenditure in British thermal units of fuel, we would be doing very well. As a matter of fact, we have actually attained a fair increase in thermal efficiency.

Experimental Work

Our experimental work was done on a 4¼ x 6-in four-cylinder 16-valve engine. At first no heat was applied to

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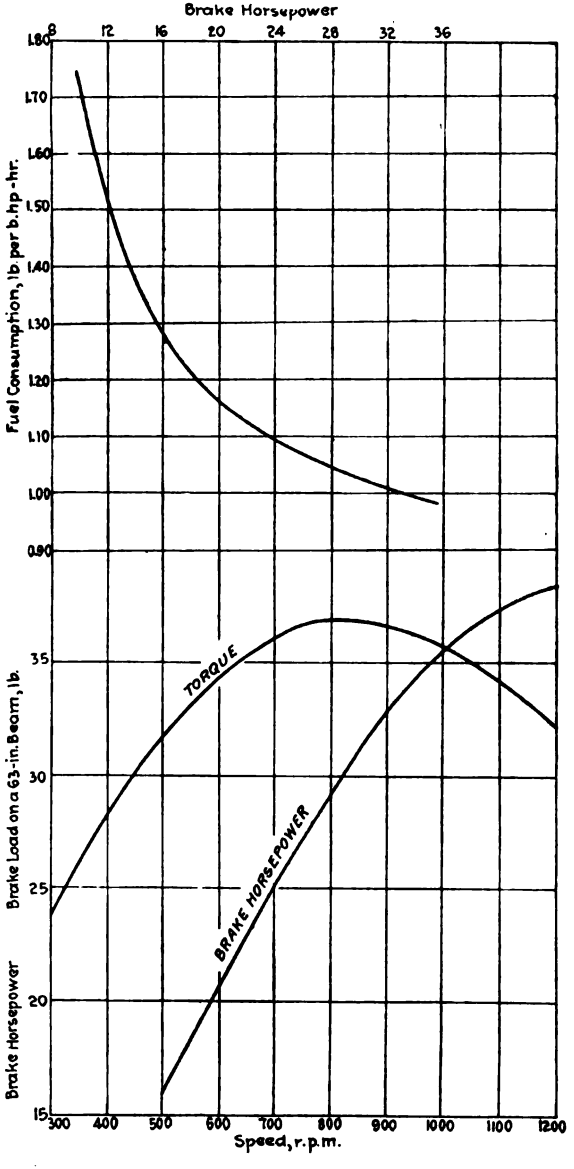

FIG. 2—CHARACTERISTIC CURVES OBTAINED WITH THE SAME ENGINE WITHOUT A SPECIAL HOT-SPOT MANIFOLD

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the intake-manifold and we were able to develop only 29 b.hp. at 1000 r.p.m., using 127-lb. gage compression, whereas we could easily develop 35 hp. with kerosene, using 63-lb. compression. When running with a cold manifold the temperature of the intake charge dropped to 35 deg. fahr., frost collected on the manifold and water froze on certain portions of it. It was necessary to choke the carbureter to a considerable extent and very unsatisfactory operation was the result. We then applied heat with the result that the horsepower increased from 29 to 35 and operation was very much improved, although the engine would not pick up its load at low speeds.

An intake-manifold with glass inserts that was used showed that a large amount of unvaporized fuel was going into the engine. We then increased the heat still more by connecting two air-heaters for the carbureter intake in series. This dried out the mixture but reduced the horsepower from 35 to 33, although the fuel consumption was decreased 1 lb. per b.hp-hr. With this set-up the inlet air to the carbureter reached a temperature of 210 deg. fahr., but after being carbureted the intake gas temperature dropped to 138 deg. fahr. with an exhaust gas temperature of 215 deg. fahr. We then decided to drop the compression pressure to 100 lb., with the result that nearly equal horsepower was developed, the fuel consumption was not increased and the operation was improved at low engine speeds.

We then tried an intermediate compression, using 110 lb., which was finally adopted as giving the most satisfactory results. With this compression we had no difficulty in obtaining an output of 35 hp., which was equal to the power developed when using kerosene. The fuel consumption at maximum load remained at 1 lb. per b.hp-hr. The alcohol used in this experimental work contained 10,500 B.t.u. per lb. We therefore consumed 10,500 B.t.u. per b.hp-hr., which, if transposed into an equivalent gasoline consumption by weight, would show a fuel consumption of approximately 0.55 lb. per b.hp-hr.. which is exactly equal to the finest performance we have obtained with this engine using gasoline and is decidedly more economical than average engine performance indicates.

The difficulties of starting are increased somewhat when using alcohol, due to the greater starting effort necessary for cranking the engine, and also because air

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at ordinary temperatures does not vaporize the alcohol sufficiently to make a good combustible mixture. Satisfactory starting was accomplished by a redesign of the starting-crank, coupled with the use of a mixture of four parts of alcohol to one of gasoline.

Conditions Necessary for Proper Use of Alcohol

In our case 110-lb. compression proved most satisfactory. Very liberal provision for heating the fuel charge must be made. The use of the entire exhaust heat will be found necessary. The temperature of the ingoing charge of fuel, for good carburetion and economical operation, should not be less than 100 deg. fahr. Careful consideration should be given to the design of the intake-manifold to obtain uniform distribution. At high compressions this is essential, especially when using alcohol. Gas velocity is important. The intake-manifold gas velocity, at full load, should not be less than 9500 ft. per min. on the average.

These are a few fundamental figures to work from. In our opinion alcohol is an ideal fuel, vaporizing at practically a constant temperature. This is a decided advantage; once the engine is properly warmed up, the operation is all that can be desired. Practically no carbon residue is created when using alcohol. The condition of the valves and valve-seats after long periods of heavy runs was surprisingly good.

We are thankful that it was necessary for us to do this experimental and development work with alcohol. In our opinion the use of alcohol as a fuel is bound to come eventually in the United States. We believe that the entire automotive industry should get behind this idea and bring it to pass as quickly as possible, so as to provide another source of fuel supply and to bring down the operating costs of all equipment depending now on hydrocarbon fuels. There are in the United States yearly millions of tons of unused vegetable matter from which alcohol could be profitably manufactured. If the automotive industry will demand the manufacture of alcohol for fuel purposes, it will head the list of automotive fuels eventually.

THE DISCUSSION

Prof. C. A. Norman:—There have been a considerable number of investigations regarding the possibility of using alcohol as a fuel for carbureting engines, and, with certain modifications of the engine, alcohol is a good

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fuel, giving a high thermal efficiency. The difficulty in America comes in supplying alcohol in quantities sufficient to play any important part in the automotive field and at prices low enough to make it competitive with other kinds of fuel.

In Germany large quantities of fuel alcohol are produced, mainly from potatoes. In this country we could do the same thing. We could also readily manufacture alcohol from corn. The yield might be about 2.70 gal. of alcohol per bu. of corn and about 0.75 gal. per bu. of potatoes. This would mean that about 5 to 10 per cent of the total farming acreage in this country, if cultivated with only moderate skill, would be enough to supply almost the whole automotive demand for fuel. It would not mean a revolution in agriculture. On the other hand, to produce alcohol salable at something like 50 cents per gal. or less, potatoes would have to sell for 15 cents per bu. and corn for about 50 cents. Such prices would not be very attractive to the farmer.

The possibility of manufacturing alcohol from farm waste products such as straw and cornstalks has long been thought of and some experiments have been conducted by the United States Government to determine what can be done in this line. So far it seems that the difficulties of commercial production of alcohol from these sources are very great, and perhaps the difficulties of collection and organization of the industry are as great as those of chemical conversion.

In Switzerland an extremely interesting process for manufacturing alcohol from coal by way of calcium carbide appears to have reached the commercial stage, the cost being surprisingly low. However, to supply the automotive fuel demand of this Country by this process, about 16,000,000 hp. would have to be applied continuously through the year. Our all-year waterpower amounts to only about 25,000,000 hp.

It seems that there is in America an almost unlimited source of fuel similar to the present-day petroleum fuel in the form of shale oil. In Colorado there is an estimated supply of 20,000,000,000 bbl. of shale oil in shale of fairly high yield. In southwestern Indiana there is a reserve of 100,000,000,000 bbl. in shale yielding about 10 gal. of oil per ton; even with such low yield it appears possible to produce automotive fuel at prices much below those at which alcohol could be produced. Judging from circulars of the Colorado School of Mines, some compa-

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nies are now producing in the West shale oil on a commercial basis; some estimated figures given by apparently reputable and financially strong organizations, in California for instance, show a cost of production per barrel of shale oil lower than the present selling price of crude petroleum.

Nevertheless, alcohol as a fuel is of great interest in the foreign field, which at the present time is attracting more and more attention from American business, and for this reason as well as on account of the more or less special cases where alcohol can be used as a fuel of secondary importance in this Country, experiments and preparations such as those undertaken by Mr. Scarratt are of value. In this connection it may be of interest to recall the rather striking fact that the best all-round fuel mixture developed in Germany during the war consisted of benzol, alcohol and kerosene in equal proportions.

F. C. ZIESENHEIM:—Will Professor Norman give us some idea of the composition of shale oil?

PROFESSOR NORMAN:—The composition of shale oil in Colorado, as determined by Mr. Winchester of the Bureau of Mines, is somewhat similar to that of Pennsylvania crude oil. It seems desirable in view of the present fuel situation to develop an automotive engine capable of burning any kind of liquid fuel, non-volatile as well as volatile. If shale oil generally were of a composition similar to that stated by Mr. Winchester, it would furnish a great quantity of fuel capable of being consumed in carbureting engines.

D. R. HARPER:—The process of producing alcohol from farm waste or any similar source is inefficient in so many ways that it is probable that a zero cost of raw material would not balance the losses inherent in the process. The primary process, namely, fermentation, is of a biological and not an engineering nature. We have virtually no control over its efficiency, and unfortunately it is a relatively ineffective process. Until the biologist knows much more about fermentation the engineer or alcohol technologist must remain content to take what nature gives him, which happens to be a rather weak liquor. Inasmuch as we start with a weak liquor, we must have distillation. The heat units necessarily consumed in this stage are so vastly many times more than we can expect to get back from alcohol as a fuel that there is an incentive to apply the distillation power source in some more efficient channel. Deep-seated natural reasons underlie

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the difficulties met by the alcohol production engineer; for example, inability to keep his plant busy long enough during the year to pay the interest charges. We cannot prod him to such great efficiency while the plant does work as to overcome the handicap of intermittent operation. The waterpower production method mentioned by Professor Norman is of interest as eliminating the biological factor and providing a process that is apparently more nearly under control.

D. L. ARNOLD:—We may not need to produce alcohol for engine fuel within our own lifetime but our children may have to produce it. When it is produced it will be a matter of by-products; alcohol alone will not be produced. The whole process must be taken into consideration in connection with the cost of producing alcohol.

An interesting method of getting power from straw and similar refuse products has been demonstrated in northern Canada. The trouble with the process is that no one has found a way to condense the gas that comes out of the straw. The heat value is there and some day somebody will find a way to do that. At present lampblack is obtained at the rate of about 400 to 600 lb. per ton. The price is 10 to 15 cents per lb. On a by-product basis the manufacture should not be too expensive.

F. F. CHANDLER:—With reference to Mr. Scarratt's experiments on alcohol, what did he find regarding so-called preignition?

A. W. SCARRATT:—There is absolutely no preignition.

CHAIRMAN E. A. JOHNSTON:—A prominent farmer near Chicago, who cultivates several thousand acres, suggested he would like to produce alcohol for power purposes from waste vegetable matter. I cooperated with him to some extent in looking up apparatus and the cost of production, but when we learned the details of the Government requirements covering the production of alcohol, we decided to give the matter up.

MR. SCARRATT:—I am optimistic regarding the fuel question. We have made very little use relatively of our knowledge of chemistry. We have ahead of us an enormous field in which we can be sure that the chemists will take a very active part within the near future. Within 5 years we will have revelations regarding fuel that will set aside all the anxiety we have at present.

CHAIRMAN JOHNSTON:—Under the present state of development the automotive engine, properly designed

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and constructed, will consume about 0.63 or 0.65 lb. of kerosene per hp-hr. and about 0.52 or 0.54 lb. of gasoline under favorable conditions.

Alcohol is fine fuel to use; one need not worry about the carbonization. It burns well; of course, it has some disadvantages, but this is true of every fuel we deal with.

NEBRASKA TRACTOR TESTS

By Oscar W Sjogren[1]

Before taking up the results of the tests, the author states briefly the provisions of the Nebraska tractor law, the kind of tests conducted and the equipment used.

Applications covering 103 different tractors were received during the season; of the 68 that appeared for test, 39 went through without making any changes and 29 made changes. The results of the tests are described and illustrated by charts.

The fuel consumption was studied from the three different angles of volumetric displacement, engine speed and the diameter of the cylinders, the tractors being classified accordingly and the results presented in charts which are analyzed. The weaknesses of the tractor as shown by the tests are commented upon at some length with a view to improvement of the product.

Before taking up the results of the Nebraska tractor tests, I believe it would be well to state briefly the provisions of the law, the kind of tests conducted and the equipment used, so that you may have somewhat of an idea of why and how the work is carried on.

Provisions of the Nebraska tractor law are as follows:

(1) A stock tractor of each model and type sold in the State shall be tested and passed upon by a board of three engineers under State University management

(2) Each company, dealer or individual who offers a tractor for sale in Nebraska shall have a permit issued by the State Railway Commission. The permit will be issued after a stock model of the tractor has been tested by the University and the performance of the tractor compared with the claims made for it by the manufacturer

[1] M.S.A.E.—Professor of agricultural engineering, University of Nebraska, Lincoln, Neb.

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(3) A service station with a full supply of replacement parts for any model of tractor sold in the State shall be maintained within the confines of the State and within reasonable shipping distance of customers

(4) Enforcement of the provision of the law is placed in the hands of the State Railway Commission

The official test includes a series of runs or tests as follows:

(1) Twelve-hour limbering-up run, beginning with one-third load and gradually increasing the load until the tractor pulls practically a full load for the last 3 of the 12 hr. The object of this test is to give an opportunity for the tractor to limber up under the supervision of a factory representative

(2) Brake-horsepower test at the rated load and speed for 2 hr. This gives an opportunity to observe the behavior of the tractor under its rated load and also gives a record of the fuel consumption

(3) Brake horsepower for 1 hr. at a load varying from the maximum to no load for 10-min. periods with the engine set as for the rated load test. This test continues for 1 hr. The object of this test is to show the fuel consumption under variable load and the speed control of the governor

(4) Brake-horsepower test at maximum load for 1 hr. with the governor set to give full opening of the throttle-valve and the carbureter adjusted to give the maximum power at the rated speed

(5) Brake-horsepower test at one-half load for 1 hr. with the governor set as for its rated load and the carbureter adjusted for the most economical operation at this load

(6) Drawbar-horsepower test at the rated load for 10-hr. continuous run. This test is carried out on a half-mile cinder track, the load being the Nebraska dynamometer car which will be explained briefly later

(7) Maximum drawbar-horsepower test. This test consists of a series of short runs with an increase of the load for each run until the engine is overloaded or the drive-wheels slip excessively. We are contemplating making a change in this maximum test for the coming season, namely to continue it through a period of 1 hr. with the maximum load which the tractor will pull for that time. The purpose of the maximum drawbar test as conducted during last season was to determine what load the tractor could pull for short distances

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(8) Miscellaneous test. This includes an investigation of work on inclines, turning radius, effectiveness of brakes, or any other feature which may seem to require special observation

The tractors are under observation throughout the complete test as outlined above. The length of the official tests varies from a minimum of 28 to a maximum of 54 hr.

Equipment Used

To carry out the work properly it was found that a special building would be necessary, inasmuch as no building was available, upon the campus, suitable for the purpose. A hollow-tile building was constructed, having a width of 41 ft. and a length of 82 ft. with 14-ft. ceiling. The question of ventilation and providing of outside air was gone into and to provide as free movement of air as possible very large door openings were used and an abundance of windows provided. The outside walls of the testing shed contain approximately 2340 sq. ft. of wall space. Of this area 294 sq. ft. consists of windows and 232 sq. ft. of door space, making a total of 526 sq. ft. of window and door openings, or approximately 22 per cent of the wall space. Besides this, two ventilators, in which exhaust fans are installed, are placed in the ceiling.

All brake tests were made on a Sprague electric dynamometer of 150-hp. capacity. This dynamometer is driven through an extension shaft mounted on ball bearings carrying a pulley 10 in. in diameter with a 12-in. face. No allowance is made for belt loss. Various types and sizes of belt are available to provide the builder with what he deems to be most suitable for his tractor, or he may provide his own belt if he so desires. Besides the dynamometer and the belts, various other equipment, such as scales, scale tanks, weighing-stands, speed-counters, tachometers, fuel-testing equipment, etc., is provided.

The drawbar tests were made on a half-mile cinder track, the surface of which is slightly rolling, no grade, however, being greater than 3½ per cent. To provide a load on the tractor which could be fairly well controlled at all times a special dynamometer car or loading machine was constructed which in the main consisted of a tractor chassis, carrying an electric generator mounted in place of the engine. This generator is driven from the drive-wheels as the car is pulled by the tractor. This machine

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furnishes a maximum drawbar pull of about 5000 lb. When it is necessary to provide a greater drawbar pull than this, various loads are attached behind the car until the desired pull is obtained. The 10-hr. continuous run demanded by the law makes this part of the test the most difficult of all the runs.

A word may be said here of the operators in order that it may be understood that the various machines were operated by the same set of operators while records were taken. On the preliminary run a representative of the tractor firm operated the machine to be sure that it was working properly. On all other tests the University furnished its own operators, as this was thought to be the most satisfactory to all concerned.

Results of the Tests

Applications covering 103 different tractors were received for the season. Of these 68 appeared for test,

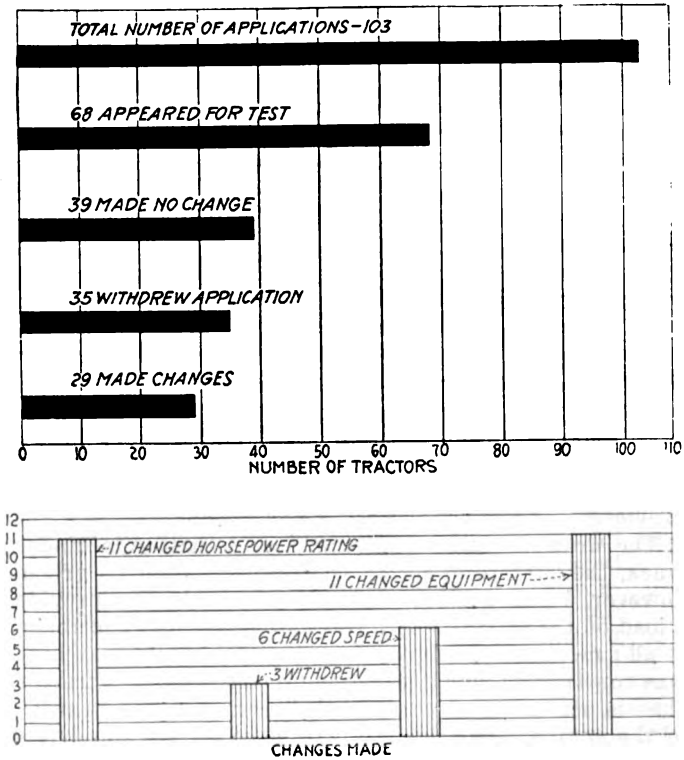

Fig. 1—Summary of Tractor Tests

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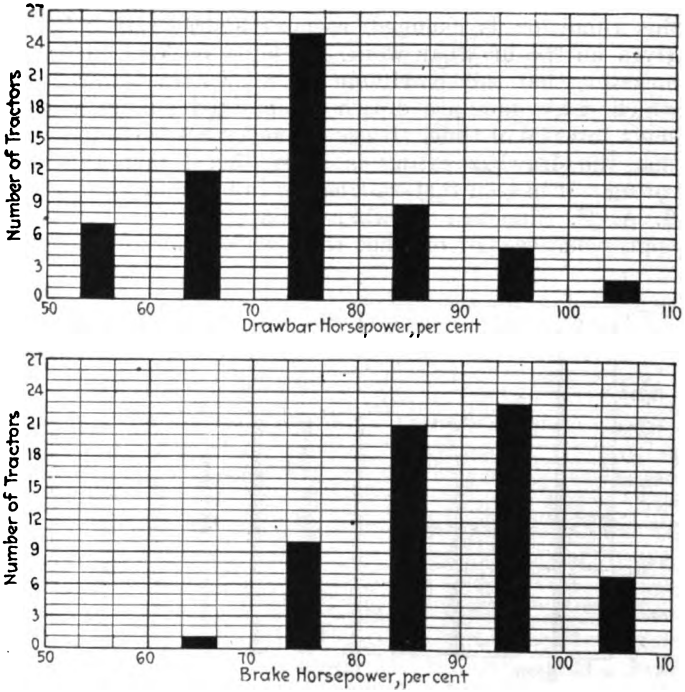

FIG. 2—RATED DRAWBAR AND BRAKE HORSEPOWER IN PERCENTAGES OF THE MAXIMUM DELIVERED IN THE TESTS

35 withdrew their application without appearing for test. The reasons for withdrawal were various, such as models becoming obsolete, curtailing of production, restriction of territory, etc. Of the 68 which appeared for test 39 went through without making any changes, while 29 made changes as indicated in Fig. 1. Of the 11 which changed equipment, 2 also changed their rating. One of the three which withdrew later made reapplication, appeared and went through the test.

In the figures covering the belt horsepower and the drawbar horsepower the maximum delivered at the brake or drawbar has been used as a basis of 100 per cent and the rating is therefore given in percentages of maximum in Fig. 2. Three tractors were not rated and two have discontinued the belt rating. It is seen that only 11 machines come within the former S. A. E. Standard belt rating, while 51 machines carry a rating higher than was permitted by that standard.

Studying the results of the drawbar tests, we find that

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this condition is changed, a more liberal rating being given on the drawbar work. It must be kept in mind, however, that this maximum drawbar horsepower from which these data are drawn is obtained during a very short interval of time. It serves, nevertheless, to indicate that the drawbar rating is more liberal than the belt rating. It is seen that 44 tractors fall within the former S. A. E. Standard drawbar rating, 7 being rated at approximately half of what they can do and 16 carrying

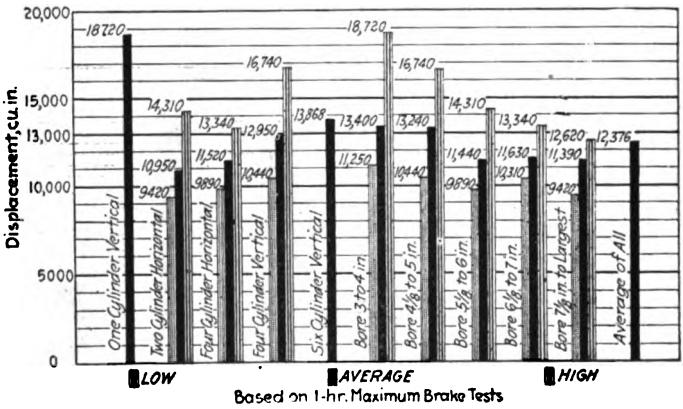

FIG. 3—PISTON DISPLACEMENT PER HORSEPOWER-HOUR IN CUBIC INCHES FOR VARIOUS CLASSIFICATIONS OF TRACTORS

a rating higher than the said standard indicated, 2 of these being rated at more than they can actually develop.

A chart compiled showing the cubic inch displacement per horsepower of various classifications of tractors and reproduced in Fig. 3 gives some interesting comparisons. These cubic inch displacement figures are all taken from the 1-hr. maximum belt test. Of the 65 tractors tested the lowest piston displacement is 9420 cu. in., which is for a two-cylinder horizontal machine. That this type, however, does not have a lower piston displacement than the other types is shown by the chart. The highest piston displacement is 18,720, which is for a one-cylinder vertical machine. This figure, being from only one machine, should not be taken as conclusive that all one-cylinder tractors have a high displacement. It is noted that there is almost a 100 per cent variation in the piston displacement shown by the lowest and the highest, and

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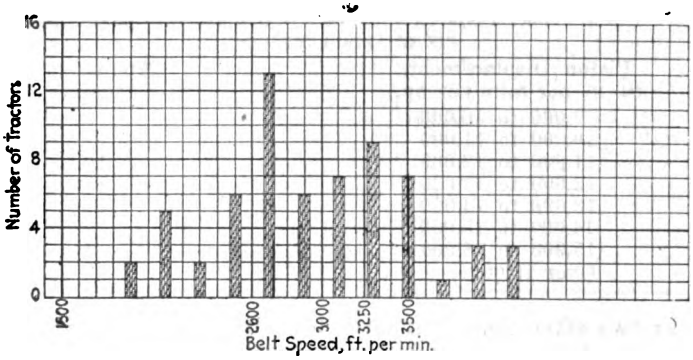

FIG. 4—CLASSIFICATION OF TRACTORS ACCORDING TO BELT SPEED

that there is a great variation in each class as to the two classifications shown.

In the classification of tractors as to belt speed in feet per minute the results obtained are shown in Fig. 4. The standard belt speeds of 1500, 2600, 3000 and 3500 ft. per min., as adopted by the Society, and the additional speed of 3250 ft. per min., adopted by the National Implement and Vehicle Association, are shown at the base of this chart and are indicated by the heavy vertical lines. It will be interesting to compare the belt speeds a year

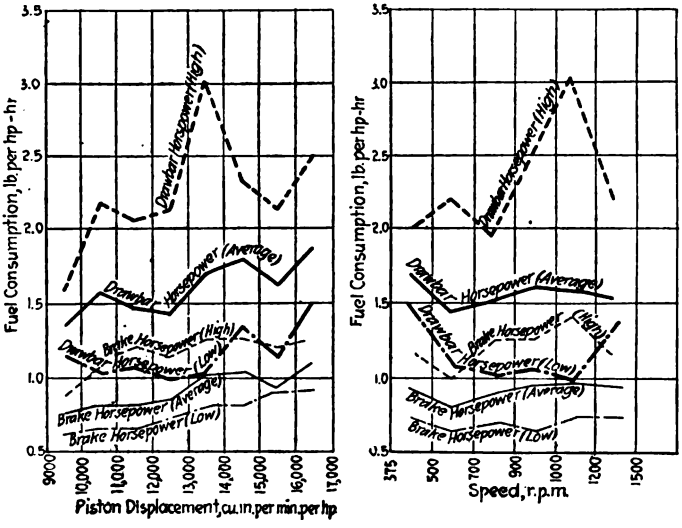

FIG. 5—FUEL-CONSUMPTION IN POUNDS PER HORSEPOWER-HOUR BASED ON THE PISTON DISPLACEMENT IN CUBIC INCHES PER MINUTE PER HORSEPOWER AT THE LEFT AND AT THE RIGHT ON ENGINE SPEED

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TABLE 1—CLASSIFICATION OF TRACTORS ON BASIS OF PISTON DISPLACEMENT

Piston Displacement, cu. in. per min. per hp.	Number of Machines
9,000 to 10,000	3
10,000 to 11,000	7
11,000 to 12,000	10
12,000 to 13,000	19
13,000 to 14,000	12
14,000 to 15,000	7
15,000 to 16,000	4
Over 16,000	3

or two after these standards have been in operation and note whether any effort is made to conform to the standards.

Fuel-Consumption

The fuel-consumption has been studied from the three different angles of volumetric displacement, engine speed and the diameter of the cylinders. The curves reproduced in Figs. 5 and 6 do not happen to be smooth, but they indicate in a general way the relation of fuel consumption to those three factors. The lowest fuel consumption secured during the season on belt work was 0.63 lb. per hp-hr. with an air temperature of 58 deg. fahr., and the highest was 1.27 lb. per hp-hr. with an air temperature of 100 deg. fahr. On the drawbar work the lowest was 0.98 lb. per hp-hr. with an air temperature of 76 deg. fahr., and the highest was 3.02 lb. per hp-hr. with an air temperature of 89 deg. fahr. Table 1 gives the number of tractors in each class according to piston displacement.

Based on engine speed, it will be seen that the fuel consumption tends to increase with the engine speed, although the difference is not great. The average shows a minimum of 0.8 lb. per hp. at about 600 r.p.m., it being greater at both higher and lower speeds. The number of tractors in each class is given in Table 2.

Based on the diameter of the cylinders, the fuel-con-

TABLE 2—CLASSIFICATION OF TRACTORS ACCORDING TO ENGINE SPEED

Speed, r.p.m.	Number of Machines
375 to 500	3
500 to 700	11
700 to 900	16
900 to 1,000	14
1,000 to 1,200	15
1,200 to 1,500	5
Above 1,500	1

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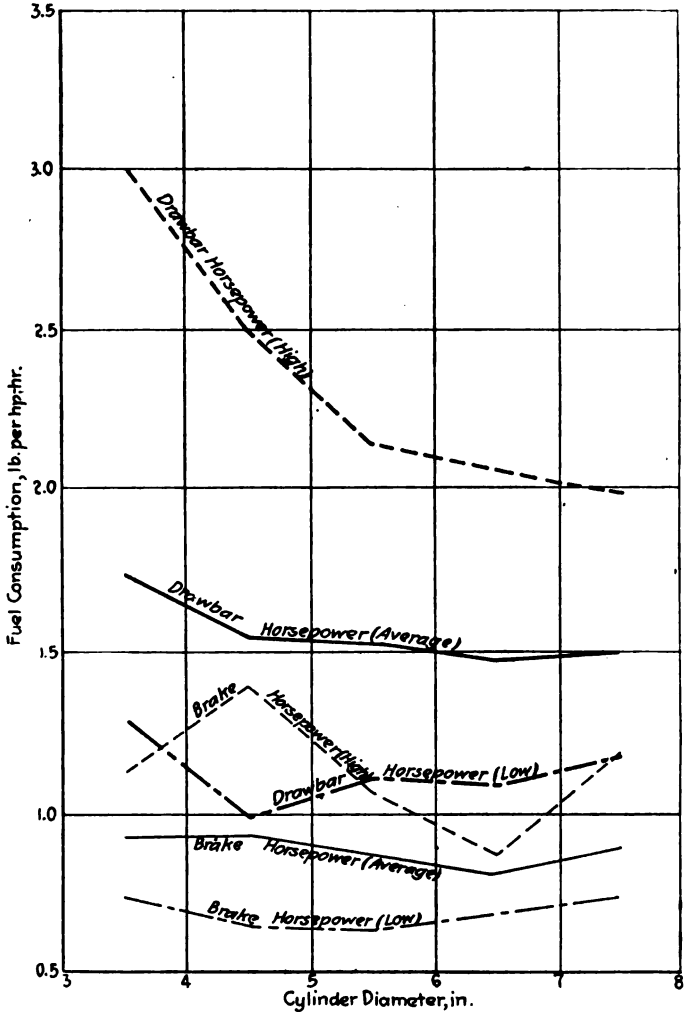

FIG. 6—FUEL-CONSUMPTION BASED ON THE DIAMETER OF THE CYLINDERS

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sumption shows a tendency to decrease as the diameter of the piston increases until the 7-in. diameter is reached. As the diameter increases above that figure there seems to be a tendency for the fuel consumption curve to start upward. The number of tractors for this classification is divided as shown in Table 3.

TABLE 3—TRACTORS CLASSIFIED ACCORDING TO CYLINDER DIAMETERS

Cylinder Diameter, in.	Number of Machines
3 to 4	13
4⅛ to 5	28
5⅛ to 6	9
6⅛ to 7	8
Above 7	7

The water consumption per hour for the different tractors showed wide variation, running from no water used during the 2-hr. rated test at an air temperature of 84 deg. fahr. to 50 gal. for the same test when the air temperature rose to 88.5 deg. fahr. On the drawbar test the amount of water required varied from nothing at an air temperature of 77 deg. fahr. to 17.8 gal. per hr. with an air temperature of 87 deg. fahr.

Weak Spots

The weaknesses of the tractor are not discussed here with the idea of criticizing the builder, for we all know that he has enough troubles of his own, but rather with the thought of singling out some of the weaknesses that have been shown up in our work in Nebraska, in the hope that this will help to improve the product.

Some of the changes that were made while the tests were in progress were a direct result of placing the tractors in the hands of operators who had not worked with them at the factory and as a consequence were not familiar with every little peculiarity of the particular machine. Some of the weaker points which may have escaped the notice of the designer or which have been ignored have thus been brought out. No changes whatever were made as a result of incompetent operators; in every case the machines had a fair trial at the hands of the operators under the observation of the tractor representative. It has been noted throughout our tractor testing work that doubtless in many cases as the tractors

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have been tested at the factory defects have been overlooked by the tractor engineer in his desire to obtain results, and as a consequence when the tractor gets into the hands of the actual user trouble develops altogether too soon. I believe that much good would result if the tests at the factory could be run by men who have had nothing to do with the design of the machine and would therefore not be apt to pet it through the test.

Probably more trouble was found with fan-belts than with any other one thing and yet this appears to be a difficulty that could easily be remedied by increasing the size or altering the shape of belt or making changes in the type of fan drive. In other cases where difficulty was had to secure proper cooling a larger radiator or a larger fan was installed which improved materially the behavior of the tractor under load. In one instance it was found that the fan was of smaller diameter than called for by the specifications. It developed that a supply of these fans had been furnished to the builder of this tractor. For some reason they were not turned back but were used and as a result trouble developed when the tractor was put under a heavy load. Other cooling difficulties indicated that the water space, especially in the cylinder-heads, might be too small. This was indicated by the heads becoming very hot, giving considerable spark-plug trouble, and yet the cooling water did not reach a temperature of 200 deg. fahr.

That the problem of the amount and degree of heated air to be taken into the engine is not yet solved is indicated by the many cases where difficulty was had in maintaining the power of the engine as it became warmed-up. During the warming-up period the engine would perform well, holding its required load, but as the temperature of the cooling fluid became constant and the engine was working hard, the power output began to drop. Trials were then made by installing by-passes and shrouds which permitted the taking in of cold air in various amounts. It was found that if as the engine warmed-up the amount of heated air admitted could be cut down and the amount of cold air increased, the power output could be maintained. This led some of the firms to install automatic air-heating regulating devices on their tractors with good success.

In some cases when it was impossible to obtain the rated horsepower from the engine, changes were made in the make and type of carbureter with very good results.

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This shows that close attention must be given to the choice of carbureter.

Where water is mixed with the fuel some method is necessary to give a close control of the amount supplied for this purpose. This was brought out very strikingly in some cases. In one instance in particular I recall that the engine would not develop within 2 hp. of its rating. By substituting a needle-valve for a globe-valve in the water line and adding a sight feed, the amount of water added could be regulated very closely, enabling the engine to develop power slightly above its rating.

Much remains to be learned about the design and use of air-cleaners. With the dry air-cleaners the most frequent difficulty seemed to be an effort to use a size entirely too small for the tractor, resulting in power below the rating. By disconnecting the cleaner in such instances the engine could develop its rating. The question of size is important also with the moist air-cleaners, as is the matter of replenishing the water supply while the engine is in operation. This latter is especially important when working the tractor on the belt. The farmer dislikes very much to have to stop the machine at frequent intervals to replenish the water in the cleaner and after some experience of this kind will likely disconnect it, thus losing the protection that it is supposed to provide.

It is probably superfluous to mention the inadvisability of the use of kerosene in a gasoline engine and yet it is permitted in some tractors with anything but satisfactory results. I believe that the builder of the gasoline tractor would save himself a lot of grief if he would discourage the use of kerosene in such a tractor.

The purpose of a governor on an engine is to prevent any appreciable variation in the engine speed. In many cases "governor" was a misnomer, while in others splendid results were obtained. The closest regulation given by any governor had a variation of 0.4 per cent above and 0.9 per cent below the rated speed. In this case the governor was set to give the rated speed of the engine while idling. The greatest variation was 55 per cent above the rated speed. Of the 65 tractors tested, 30 had governors which gave a speed regulation within 10 per cent of the rated speed, and 35 went above this figure. Of the latter, 13 varied more than 20 per cent and two more than 50 per cent above rated speed. In no case did the variation below rated speed exceed 7 per cent.

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A study of the log sheets giving readings every 10 min. seems to indicate a close relation between the speed control and the fuel consumption. Where there is a fluctuation in the engine speed on the 2-hr. rated load test there is a corresponding fluctuation in the fuel consumption at each 10-min. interval and likewise where the speed is practically constant throughout this test the fuel consumption readings at the 10-min. intervals are more nearly constant. It seems, therefore, that in the interest of fuel economy a close regulating governor is desirable.

Belt pulleys of the types which can be attached or taken off readily gave considerable trouble. This is no doubt due to their having a short shaft and usually only one bearing. The pressure upon such an arrangement is large and subjects it to severe usage.

There was lack of proper clearance in some cases between the face of the belt pulley and the drive-wheels. Under wet-soil conditions this may give considerable difficulty by the filling on the drive-wheel rubbing on the belt pulley, thus causing a stalling of the engine. A desirable arrangement of the belt pulley and starting provision which is lacking on some tractors is the ability to crank the engine and start it while in the belt. This is very desirable from the standpoint of a "one-man machine."

The weight distribution or method of attaching the load or both are often such as to make the weight on the front wheels too little and as a result these wheels do not bear down upon the soil heavily enough to cause the tractor to turn readily, especially when pulling a heavy load. The guiding mechanism is in constant use while the tractor is operated on drawbar work. In view of this fact, it should be designed so as to be operated more easily on a number of machines.

More attention should be given to providing means for the operator's comfort and convenience in the matters of seat design and arrangement and accessibility to the various parts of the tractor for inspection, adjustment and repair. Often the seat is placed directly in the path of the fan blast, without any effort being made to deflect this blast of hot air and, consequently, the operator must endure this heat in addition to the hot weather during the working seasons. In other instances the operator is compelled to be seated astraddle of a transmission case which virtually becomes a boiling volcano. The matter of replenishing the supply of water in

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the cooling system and in the air-cleaner, as well as lubricating the tractor while it is in operation, seems to have been overlooked in a number of instances.

That the condition of the valves is looked upon by the factory as a minor matter is indicated by the fact that in 16 different tractors the valves were ground after the test was started, the power output being thereby materially increased. A number of these cases gave evidence of the work of fitting and grinding the valves having been improperly done at the factory. It should be remembered that the farmer and often the service man do not have at their disposal the equipment for this work that is available at the factory, and this should be given proper attention there. The farmer expects the newly purchased tractor to serve without the necessity of immediate attention to such matters and rightly so.

That the matter of proper spark-plugs has not been satisfactorily solved is shown by the records which disclose that 42 spark-plugs had to be replaced during the testing season. This in itself is not indicative of any serious difficulty in this respect, but when it is noted that the trouble was due to the points burning or breaking off and the blowing out of plugs, it indicates that some builders have not found a plug that works satisfactorily in their machines.

The changes made necessary in the large percentage of the tractors submitted for test indicate that the power ratings are made on too narrow a margin. Other tractors went through the tests with a very liberal margin above their rating. This wide difference should be eliminated and ratings made on a uniform basis. The sooner this is done the better it will be for the industry, as it will eliminate a large amount of suspicion on the part of the purchaser. If he can feel certain that a 30-60 tractor of one make is equal in power to a similarly rated tractor of any other make, he will have more confidence than he has now. The results of the test allow a comparison to be made of tractors using the same make and model of engine. For instance, three different tractors use the same 3⅛ x 4½-in. engine and are rated differently as is brought out in Table 4.

Here is a variation in rating of *A* and *B* of more than 8 per cent and yet they have the same engine operating at the same speed. Tractor *C* is rated lower on the belt than *A* and yet the engine is operated at a greater speed. It is plainly evident that here are differences in rating

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TABLE 4—DIFFERENCES IN THE RATING OF THREE TRACTORS USING THE SAME ENGINE

Tractor	Rating, hp.	Speed, r.p.m.	Maximum Belt Power, hp.	Drawbar Pull, lb.	Speed, m.p.h.	Power at Drawbar, hp.
A	6 to 12	1,000	12.37	1,142	2.06	6.27
B	5 to 10	1,000	11.34	1,189	1.79	5.66
C	6 to 10	1.200	13.31	1,310	2.84	9.92

for which there are no consistent reasons. The same condition holds true though not so markedly with larger tractors using an engine of the same make and size.

To sum up what has been said, the difficulties can be classified into five divisions. These are (*a*) engine troubles, which are dependent upon the design of the engine and the correlation of different parts; (*b*) accessory troubles, which depend upon the choice of the proper accessories and their adaptation to the engine; (*c*) proper correlation of the parts and the design of the chassis to fit the engine and permit the most efficient use of it; (*d*) testing of finished tractors by others than designing engineers to bring out minor difficulties; and (*e*) rating the tractors to give a liberal allowance for overload.

THE DISCUSSION

G. R. PENNINGTON:—The tractive force or total force exerted against the ground which a tractor can develop is a constant. The maximum available drawbar pull is equal to this tractive force less the force required to move the tractor itself and is therefore a variable depending upon soil conditions. In certain cases we are more interested in knowing the tractive force or tractive horsepower than the drawbar pull or drawbar horsepower available. A usual way to determine the maximum tractive horsepower is to measure the drawbar horsepower and add to that the power necessary to pull the tractor itself at the given speed. Have you tried that method?

PROF. O. W. SJOGREN:—No. We tried to test the tractors in the same way the farmer would use them.

A MEMBER:—The test sheet shows that the prevailing fuel was kerosene. It has been brought to the attention of many that there is a growing aversion to the use of kerosene as it is handled in the present carbureter system. What is Professor Sjogren's opinion as to the economic status of low-grade fuels?

PROFESSOR SJOGREN:—I do not know that I am in a position to give a definite answer to the question. The

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amount of gasoline used was practically the same as the amount of kerosene. We get practically as much horsepower from a gallon of kerosene as from a gallon of gasoline, provided the tractor is designed for kerosene.

MR. PENNINGTON:—Does the increase in crankcase oil dilution, which we get with lower-priced fuels, make up for the difference in price between kerosene and gasoline?

PROFESSOR SJOGREN:—I believe it does not.

PROF. W. T. MAGRUDER:—I would like to know why due allowance was not made for the power lost in transmission between the belt pulley and the dynamometer.

PROFESSOR SJOGREN:—Because we want to know what amount of power the farmer can take off; also because there was no definite rule for determining the loss without making a calibration of each machine. We discussed that for a long time before we arrived at our conclusion; we decided that, to be fair to everyone, the best method was to measure the power at the brake end.

PROFESSOR MAGRUDER:—Tests show that it makes a considerable difference how the power is taken off. For accurate results the dynamometer should be tested and the pull of the tractor on it standardized; otherwise results differing by 1 to 2 hp. will be obtained, which is a large percentage of the gross power.

CHAIRMAN E. A. JOHNSTON:—Most engineers appreciate the fact that belt power losses vary considerably under different conditions of transmission. Unfortunately many manufacturers have not made sufficient allowance for belt clearance. The farmer is interested in the power delivered to the belt of the driven machine, as Professor Sjogren states.

D. L. ARNOLD:—To compare the performance of all tractors the maximum drawbar pull and the maximum belt horsepower were reduced to a piston-displacement basis. On that basis I found that only two of the tractors tested fell below delivering 50 per cent of their belt power to the drawbar, while the tractors of highest efficiency came close to 82 per cent. Of course, that takes into consideration the friction of the transmission and driving mechanism to pull the tractor under load.

PROFESSOR SJOGREN:—That is probably due more to the condition of the track. We used a cinder track because we felt it could be maintained in a more uniform condition throughout the season than a dirt track, and because it was more like a stubble field.

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H. W. RILEY:—Were the lugs uniform in every case?

PROFESSOR SJOGREN:—We made no specific point of investigating the equipment. We allowed the manufacturers to use what lugs they thought worked best; they investigated that and were in a better position than we were to make the proper choice.

MR. PENNINGTON:—In view of Mr. Arnold's statement, I wish to explain the reason for my question. If two tractors, which on the cinder track develop the same drawbar horsepower, were taken out in a soft field, one tractor might then deliver much more drawbar horsepower than the other, for the reason that less horsepower might be consumed in moving this tractor itself. The amount which a tractor sinks into the ground largely governs this factor. A comparison on a cinder track is not therefore sufficient for all purposes. We are interested also in knowing the power it takes to move the tractor over any given soil. I would like to ask whether Professor Sjogren has made any measurements of that kind.

PROFESSOR SJOGREN:—No.

J. A. SECOR:—I understand that the different kerosenes and gasolines used in the tractors varied considerably. Was any average quality determined for the kerosene and the gasoline as a whole that was used as fuel for all the tractors?

PROFESSOR SJOGREN:—The variation was very slight. We struck no average.

MR. SECOR:—The average would be about 6.75 lb. per gal. for ordinary kerosene, and 6.20 lb. for engine gasoline. These weights correspond with 43.2 deg. Baumé for the kerosene, and 58 deg. Baumé for the gasoline. Lighter or heavier kerosenes and gasolines should be within 1 per cent of these averages.

A. R. SANDT:—Did Mr. Sjogren determine whether the breakages were due to poor material or to faulty engineering?

PROFESSOR SJOGREN: — I think our report specifies whether there was poor material or poor engineering, and that it runs about half-and-half. Where the report said that considerable wear was noticed, I concluded what the main difficulty was. In one case where the flywheel flew to pieces, we concluded that we could not determine whether that was due to faulty engineering or faulty material. That happened when the operators were not present. The engine was started and seemed to acceler-

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ate very rapidly. It appeared that somebody had used a wrench on it. That merely goes to show that on a test one must be very cautious and watch every detail to get accurate results. When we made mistakes in our testing work, we tried to remedy them as soon as we noticed them. We did not get all the information we should have secured because of the pressure of the work. You can imagine what it means to have 103 tractors to test during a season, each one of which must be run from 20 to 50 hr.

A. W. SCARRATT: — Professor Sjogren mentioned the difficulty experienced with spark-plugs generally. I do not wish to defend the spark-plug manufacturers, but if the implement manufacturers will pay a little more attention to the design of their engines, with reference particularly to carburetion, lubrication and cooling, they will not have so much trouble with the spark-plugs. We have tested nearly every reputable make of spark-plug that is not of freakish design and of all of them there are about three that we can say do not stand up satisfactorily. This may not be the case with all engines. More attention should be paid to carburetion to make it thorough and complete; to the proper distribution of the lubricant, especially to prevent excessive lubrication; and to the timing. This will help to clear up much of the spark-plug trouble.

O. B. ZIMMERMAN:—We should extend a vote of thanks to the Board of the Tractor Test Committee of Nebraska for the extreme fairness and frankness with which they carried on this whole series of tests. They have been so generous in their courtesy that I am sure all of us will have gained much information from this analysis.

The questions have indicated that there are many things we would like to have incorporated in the analysis and undoubtedly they can be incorporated in the series of tests of next year. We would like to know what the relation actually is between the maximum drawbar pull of a tractor and its weight. That is, of course, obscured by lugs, wheel diameters and wheel widths. We should give much attention to lug and wheel data from an engineering standpoint. These factors constitute perhaps the weakest point in our general understanding of design considerations today. In traveling over the ground, we must look upon the whole tractor design from two standpoints, the effect of the weight and the effect of the lugs.

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The plow itself should be designed to give a maximum disturbance of soil for a minimum expenditure of energy. The tractor itself, or the part which takes hold of the ground, should be designed with a contrary view, that of getting the minimum disturbance of soil and enabling us to transmit the greatest amount of power. In many of the tests which we are endeavoring to analyze, for instance, the relation of speed to draft, the actual data that interest us are covered up to a certain extent by the fact that altogether too often the soil is disturbed before the plow takes hold of it. That is particularly true when we use the higher speeds. Inasmuch as all these data are taken at the drawbar, we must watch with care and not upset the analysis by believing that all of this work is done by the plow, when a good share is often done by a disturbance of the lugs, perhaps by a pressure which the engine carries to it and by narrow wheels. So, I think we should look into this matter of the design of wheels and lugs very carefully. We should also pay great attention to the transmission, the engine shaft and the rear axle.

In studying these Nebraska tests, I hope the analysis will include consideration of the enormous amount of power that is lost between the engine shaft and the drawbar. It seems almost foolish to lower the fuel consumption on the brake test and then lose in the transmission seven or eight times as much as seems necessary. I think that will show that we have given excessive attention to the engines. It will be found that many engines give excellent fuel consumption in relation to the power delivered at the engine shaft, but are excelled by many other engines when the power is measured at the drawbar. I hope we will soon analyze the power losses in the bearings and the gearing and those due to wheel design and the like.

PROFESSOR MAGRUDER:—In comparing with the drawbar horsepower the horsepower delivered at rated load for 2 hr., I find that the drawbar horsepower per gallon varies from 33 to 82 per cent of the actual horsepower at the pulley. I suggest that the Research Committee investigate why we lose this large amount of power in transmission.

MR. SANDT:—Did Professor Sjogren notice any particular difference between the various types of final drive?

PROFESSOR SJOGREN:—I will ask you to take the tabulated reports and draw your own conclusions.

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A MEMBER:—I suggest that, if possible, during the next series of tests, standardized belts that are suitable for the pulley widths be used, and that the slippage on different diameters of pulley be obtained.

PROFESSOR SJOGREN:—The belt slippage was given for each test in the official reports. We shall be glad to receive suggestions from the Society as to items that should be included in our next report. We expect the coming season to be fully as strenuous as the last one was. We have had 20 requests for tests and that is about the same number we had last year at this time.

H. W. SIMPSON:—Why are some of the tractors' ratings omitted?

PROFESSOR SJOGREN:—Because the firms make no rating. The ratings shown on the chart are the manufacturers' ratings.

E. R. NASH:—Why are some of the lug data left out?

PROFESSOR SJOGREN:—Where lug data are not given, the tractors were of the crawler type, no lugs being used.

R. I. SCHONITZER:—Did the test include a record of the results obtained with different types of bearing, such as plain, ball and roller, as used in engines and transmissions of the various tractors tested. Were the results obtained with different types of lubrication system included?

PROFESSOR SJOGREN:—No, but we will be glad to include additional interesting features in future tests if the members of the Society will make suggestions.

CHAIRMAN JOHNSTON:—The tractor industry will succeed in direct proportion to our ability to make tractor operation profitable to the tractor user. This should control the trend of tractor design. In the early days it was a question whether tractors should have two, three or four wheels, or have a track. The problem, as I see it, is one of designing the tractor for greater reliability, durability and economy, and developing the usefulness of the tractor to the greatest possible extent. The tractor operator is not an engineer and cannot be expected to make frequent adjustments and replacements. The successful tractor will be designed so that it will require a minimum amount of attention other than supplying fuel, lubricant and water once or twice daily. Gear, sprocket, shaft bearing and other pressures and stresses will be kept low enough to insure durability and eliminate breakage. Obviously, only material of the highest grade should enter into the construction of the modern tractor.

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The economic use of fuel and lubricants and convenience of operation are important factors.

The Future Tractor

The future tractor should be provided with a take-off to transmit power to binders and other implements. On most farms, diversified farming is carried on to such an extent that power must be applied to many implements that cannot be operated profitably with tractors designed for heavy drawbar and belt work only. The farmer's problem is one of production and the cost of production. As the cost of labor averages 40 to 50 per cent of the total cost of production, it is clear that the production per man must be increased to decrease the cost of production. This is an engineering problem and can be solved by the proper application of automotive power to agricultural equipment. I will not attempt to say how it can be best accomplished, but will present some recent

Fig. 7—A Power-Drawn Two-Plow Outfit

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developments that have a bearing on the solution of the very important problem of the application of automotive power to agricultural equipment.

This power machine is designed with two drivers, and can be operated in either direction. The plows can be attached and detached conveniently and quickly. The operator's seat is rather high, as can be seen from Fig. 7, but he is up out of the dust. That is one of the advantages. One of the drive-wheels operates in the furrow, which is beneficial under some conditions, in fact, under most conditions. The same tractor operates a four-row corn-planter, planting about 2½ times as much acreage per man as the ordinary two-row horse-drawn planter. The four-row planter, illustrated in Fig. 8, weighs and cost slightly more than the two-row planter and can be attached and detached quickly and conveniently. It is designed to turn short. The power-operated cultivator, shown in Fig. 9 can be attached and detached quickly and guided quickly with very slight effort by the operator. This cultivator costs about 75 per cent as much as the horse-drawn cultivator and cultivates two rows at a time.

A power-operated mower has a 14-ft. cut, twice the width of cut of the horse-drawn mower. The mower in Fig. 10 costs just about the same as the 6 or 7-ft.-cut horse-drawn mower. One operator can mow hay at the rate of 4 acres per hr., which is about three to four times the capacity per man with a team. The bars are raised quickly and automatically. Besides, there is a hay-rack with a capacity of 12 to 14 ft., increasing the capacity per man 300 to 400 per cent. All of these implements can be attached conveniently and quickly without the use of any tools or removing any bolts.

A wide power-driven sweep-rake and grain-shock gatherer can be folded up for passage through fence gates, and unfolded for operation afterward. It has a large capacity as a sweep-rake as can be seen from Fig. 11, and the same implement when gathering shocks has a capacity of from 8 to 12 grain-shocks. It gathers the shocks without shelling the grain as badly as when pitched by hand. It has a capacity sufficient to enable one operator to keep a small separator fully supplied. With it a man can do the same work that ordinarily three teams and six men accomplish. There is much lifting to be done on all farms. A power-operated derrick has been adapted to this same machine to handle hay or do other

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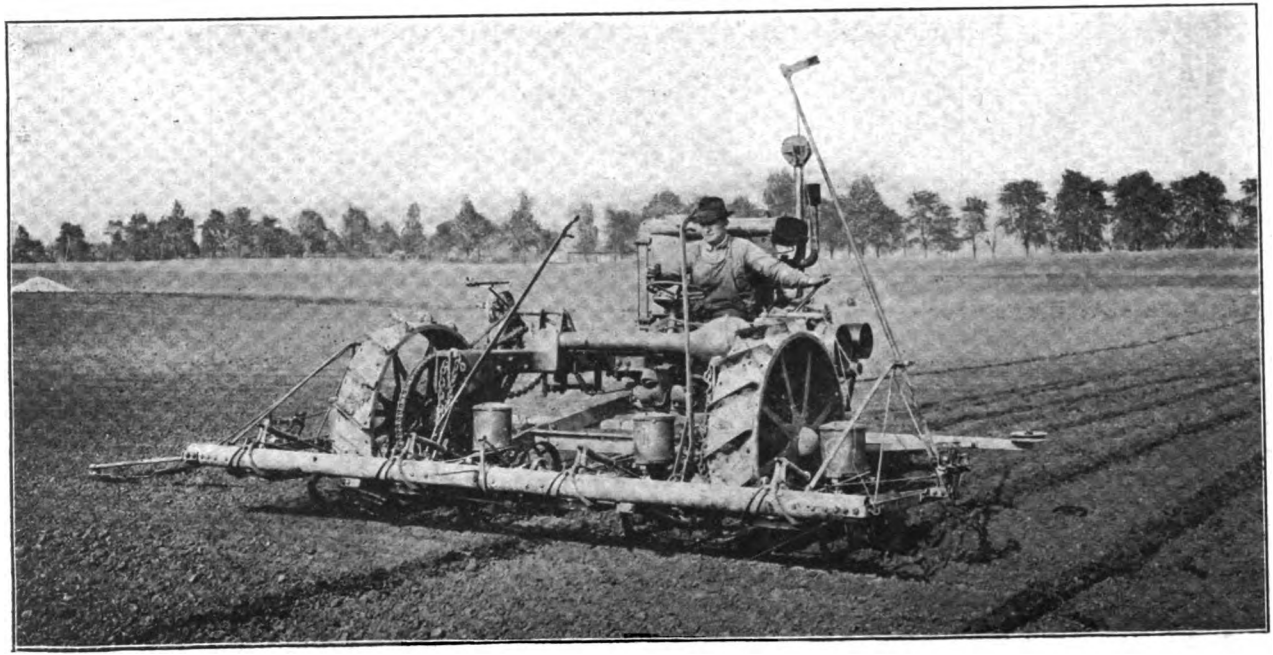

FIG. 8—A FOUR-ROW CORN-PLANTER

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lifting such as loading corn-stalks out of the field and onto the wagon. It is often desirable to remove the corn-shocks to enable the farmer to plow. Corn-shocks are very difficult to handle by hand.

The 10-ft. binder and harvester weighs and costs approximately 60 per cent as much as the conventional horse-drawn machine; it can be equipped with an automatic shocker. The same machine handles a grain-header that has an 18-ft. cut. The header weighs and costs

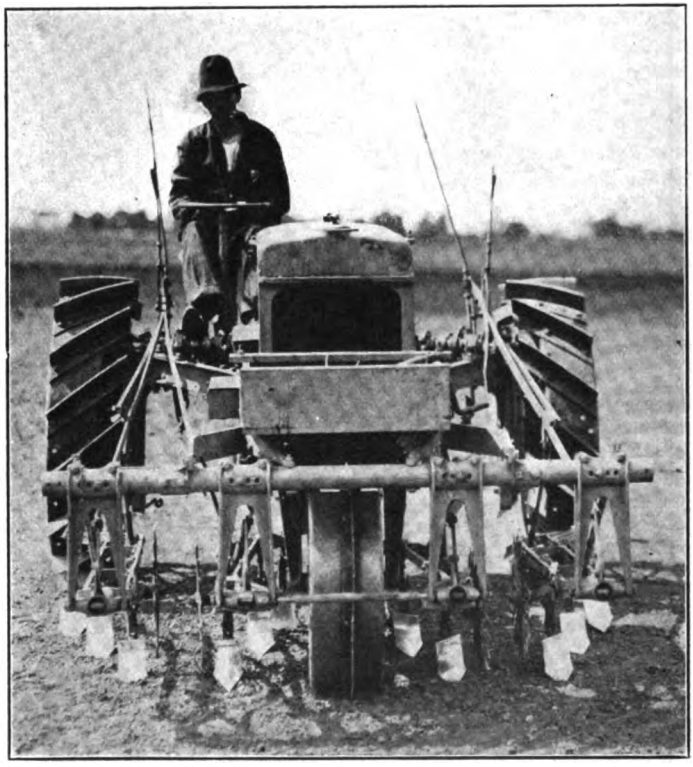

FIG. 9—THE TWO-ROW CULTIVATOR

slightly more than half as much as the regular horse-drawn implement. It has the advantage of opening up a field without tracking down the grain. This machine is an adaptation of a horse-drawn corn-picker, which weighs less than 2000 lb. as designed for use in connection with the power machine. Its operation is very much improved

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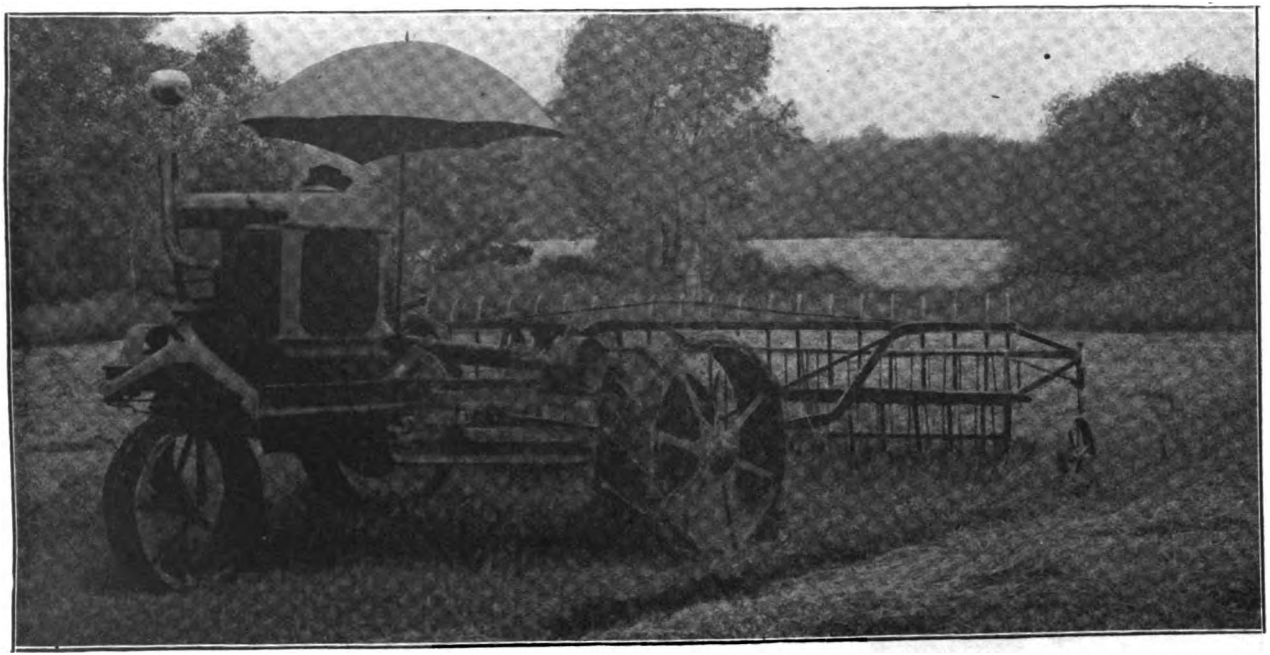

FIG. 10—THE TWO-BAR MOWING MACHINE

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FIG. 11—THE SWEEP RAKE AND SHOCK-GATHERER

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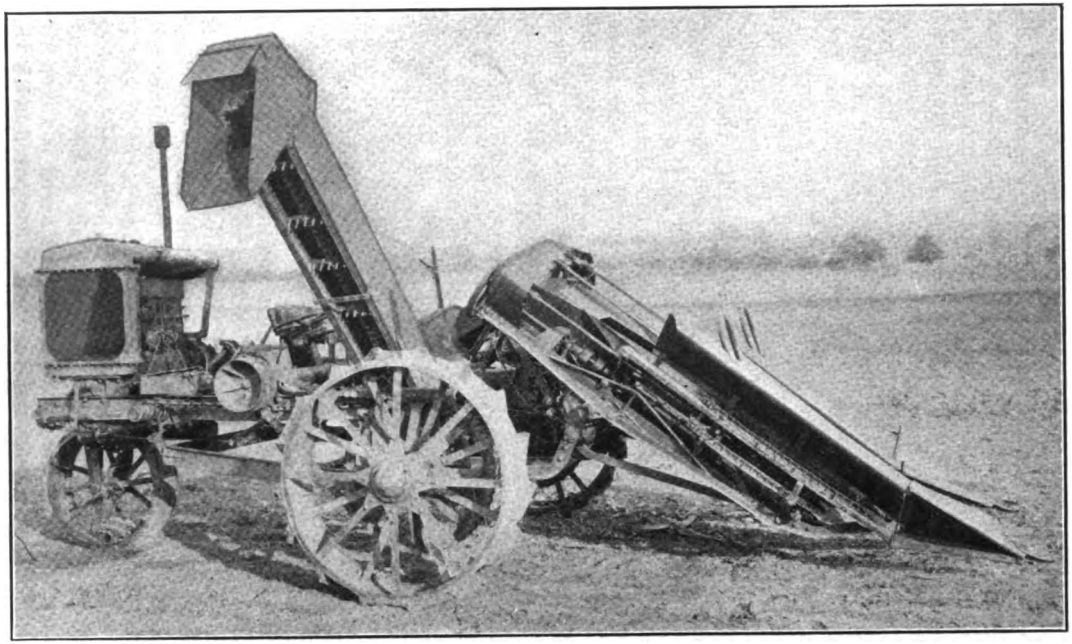

FIG. 12—A TRACTOR-OPERATED TWO-ROW CORN-PICKER

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by maintaining a uniform motion. There is also a tractor-operated two-row snapper, which picks the ears from the stalks without husking them. This machine is illustrated in Fig. 12.

With all these machines the power is transmitted directly from the engine to the machine, which is a great advantage in operation. Regardless of the movement of the machine forward, it operates at uniform speed, which results in a high grade of work.

PRESIDENT DAVID BEECROFT:—This session has given us a fine insight into the wonderful chapter of farm power. The adaptation of power to the farm has been very different from the use of power in the factory. In a large factory we have a centralized powerplant, and the power is conveyed from it to the different departments. What would we think of a factory that had a separate powerplant for operating each department? But, literally, that is what we have had on the farm. On a relatively small farm in Minnesota one man had two tractors, two motor trucks, two automobiles, one house-lighting equipment and six stationary gas engines of different sizes. Mr. Johnston has illustrated the modern thought of the unit powerplant that serves all the purposes.

F. F. CHANDLER:—On how small a farm would it be possible to use a combined equipment economically?

CHAIRMAN JOHNSTON:—It all hinges on the cost of operation. Much has been said about the cost of horse operation and it can be elaborated on to an enormous degree. To keep a horse requires the product of five acres, according to the best information available. The feed is about 60 per cent of the cost of keeping a horse, so that the value of the product required to supply the other 40 per cent means that a total of about 8 acres is required to keep a horse. It is possible, as I see it, to develop power-driven farm equipment along the lines mentioned or along some other line so that machines will replace all of the horses on the average farm of 100 to 150 acres. Usually about seven to ten horses are kept on a 150-acre farm. If there were only six or seven horses and the value of the product of eight acres is taken for each of those horses and the result compared with the cost of a power combination equipment, it will be found that the power equipment can be operated at approximately 60 per cent of the cost of operating by horses. Ultimately, of course, the cost of operation and of production will determine the answer.

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MR. CHANDLER:—That possibly answers the question as far as it can be answered at present. What I had in mind is how small a farm it is possible to operate with a tractor and combined power-driven implements; for instance, if all of the combined cost due to horse equipment were applied to power-operated implements, how would that combined value of the horse equipment compare with the combined cost of the machinery that is desired to replace it?

CHAIRMAN JOHNSTON:—One of the great advantages to be obtained by some such development is the reduction in the weight and cost of implements. The power-driven implements will cost from 40 to 75 per cent less than horse-drawn implements of equal capacity. Perhaps I can answer the question by saying that the tractor for heavy belt and drawbar work is being developed rapidly. It has been developed to a point where there is no question as to its usefulness or as to its being a profitable investment for a farmer who tills 75 acres or more. Obviously, to reach the small farms, some such development as I have described must be accomplished because, if the small farmer carrying on diversified farming can use his tractor only for drawbar and belt work, he can make profitable use of the tractor for only approximately six to eight weeks in the entire year and it will be necessary for him to keep approximately the same number of horses as before to handle his row crops, which could not be handled to advantage with a tractor developed for drawbar and belt work only. Summing the matter up, as nearly as I am able to determine, a properly developed combination outfit can be used profitably on farms of 50 acres or even less.

FRED C. ZIESENHEIM:—A farmer in Pennsylvania kept an account of the number of horse-hours used per year. He determined that the maximum number occurred in the cultivation and not in the plowing season. Nevertheless he bought a tractor for use in the plowing season, because he gained time; he gained one month last year. He was compelled, however, to keep his horses to take care of cultivation and emergencies.

MR. PENNINGTON:—Why are implements designed to be used with tractors cheaper than those intended to be pulled by horses? It seems offhand that horse-drawn implements would be cheaper since they are pulled at lower speed and can therefore be made of lighter construction.

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CHAIRMAN JOHNSTON:—On all machines designed to be pulled by horses, the power is transmitted from a ground wheel into the machine through a transmission mechanism. The weight and cost of the carrying wheels, the transmission mechanism and the construction necessary to carry that mechanism are eliminated in the implement designed to be operated by power along the lines I have described.

C. A. ATHERTON:—What are the possibilities of operating tractors at night, and the probability of equipping all tractors with electric lights as standard parts?

CHAIRMAN JOHNSTON: — That is a very interesting question. When we commenced to sell tractors 10 or 15 years ago, there was a demand for lighting equipment in the Dakotas and the prairie country. Night tractor operation was carried on to a considerable extent. In a general way the operation of tractors at night results in just the same expensive unsatisfactory operation as night work in a factory, excessive breakage and higher cost of operation per unit of work. Furthermore, there are many farming operations which cannot be done to advantage at night on account of dew and other conditions. While there is some demand for lighting equipment to operate tractors at night, it has not been sufficient to justify supplying it as standard equipment.

MR. ATHERTON:—I am not a farmer or an agricultural engineer. I am looking at the subject from an illumination point of view. It seems to me that the farmer has less choice as to when he shall work than has an operator in any of the other industries. He is more dependent upon the seasons and must work when conditions are right. It is necessary frequently for him to put in 24 hr. of work at the right time. In a late spring the farmer might have to crowd all his plowing into one-half the time that he would ordinarily devote to it.

CHAIRMAN JOHNSTON:—Your thoughts along that line are correct but in practice they must be modified. The small farmer may have one man to help him or a man and a boy or two boys. He cannot operate 24 hr. without additional help. It has been difficult to get help of any kind. On the larger farms the equipment is generally adequate to perform the farm operations at the most desirable time. There is very little demand for tractor lighting equipment at this time.

MR. SANDT:—Is there any demand for starting apparatus?

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CHAIRMAN JOHNSTON:—There is always a demand for starting apparatus or any convenience on a tractor, the same as for any other device or machine. The conventional starting device operated electrically and requiring a storage battery has not been developed to a point where it can be used generally on tractors; at least that is the attitude of most tractor designers. Starting equipment is standard on some tractors, and seems to be very satisfactory; but, in a general way, I believe that tractor development is not at a stage where it should be complicated with electric starting apparatus.

MR. NASH: — On the large farms in California and along the Pacific coast it is the practice to use the tractors at night to a great extent, and electric lighting is largely used there. A few tractors are equipped with gas light, but the most satisfactory equipment appears to be a generator of approximately constant voltage driven as seems best and operating without the use of a storage battery. One of the manufacturers brought out a gear drive for one of these generators which no doubt will prove much more satisfactory. Our most successful owners, during their plowing and seeding season or in doing discing or anything of that kind, operate 22 hr. daily for six days. On the seventh day they lay up and go over the rigs. They will not stop during the week except for an emergency.

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MOTORBOAT MEETING PAPERS

COMMERCIAL MOTORBOATS AND THE DIESEL ENGINE

By G C Davison[1]

It is stated that, in the commercial motor boat field, the boat owner must choose between the various types of internal-combustion engine, broadly speaking there being three forms of such engines available today in small and moderate sizes; (*a*) the gas engine, (*b*) the surface-ignition or hot-bulb engine and (*c*) the Diesel engine. Charts are presented which show certain approximate costs of operation of the three types for various sizes of engine.

Fuel and lubricant economy are discussed in connection with the question of the choice between a Diesel and a hot-bulb engine and, in regard to mechanical operation, it is stated that there is little choice between any of the three types under discussion, since all are reliable. For sizes of 100 b. hp. and less, some form of hot-bulb or surface-ignition engine has the field to itself, but for sizes above 100 hp. the Diesel engine shows its superiority.

The owner of a commercial motorboat is always interested in the forms of power available for its propulsion. He must have a plant that is not only reliable in operation, but one which is safe, requires a minimum of attendance and is subject to a minimum cost of operation. At the present time the internal-combustion engine is so far developed that no boat owner thinks of installing anything else in any boat which requires less than several hundred horsepower. In the larger sizes of boat requiring powers of say 300 hp. and over the choice is between steam and internal-combustion engines. Even in this field the steam engine is rapidly being replaced by the internal-combustion engine, so that it can be said that in the commercial motorboat field the boat owner must choose between the various types of internal-combustion engine.

There are, broadly speaking, three forms of internal-

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combustion engines available today in small and moderate sizes. There is (*a*) the gas engine, (*b*) the surface-ignition or hot-bulb engine, and (*c*) the Diesel engine. There are several variants of these three types, but for the purposes of this discussion only the three general types will be considered. Charts have been prepared which show certain approximate costs of operation of the three types for various sizes of engine. Before discussing these charts in detail, the basis of plotting will be given.

First Cost

These charts cover the fixed charges plus the fuel cost of operation. In establishing the fixed charges it is first necessary, of course, to estimate the cost of installation. This is variable, depending upon circumstances, but as a fair minimum the first cost has been assumed as the cost of the engine plus 15 per cent. This 15 per cent represents the cost of installing the engine in the boat complete with all piping, shafting, propellers and such auxiliaries as are necessary for the operation of the ship. In case the machinery is to be installed in an old boat, this item will be greatly increased, but the relative proportions will scarcely be changed. The first cost of the engines only has been estimated as follows:

FIRST COST OF VARIOUS ENGINES

Type and Size of Engine	Cost per b.hp.
25-hp. Diesel	$200
25-hp. Hot Bulb	100
25-hp. Gas	60
50-hp. Diesel	125
50-hp. Hot Bulb	85
50-hp. Gas	60
100-hp. and larger Diesel	100
100-hp. Hot Bulb	75
100-hp. Gas	60

In considering these costs, it must be remembered that these remarks apply only to heavy-duty engines suitable for work boats. If light-weight high-speed engines are concerned the proportions will be entirely changed. The total fixed charges for each year have been taken at 20 per cent in each case. This 20 per cent consists of 11 per cent for depreciation, 6 per cent for interest on the investment and 3 per cent for repairs. The depreciation item is perhaps rather severe on the Diesel engine, but for the purposes of this comparison it was thought better to assume the same percentage in all cases. For the 100-hp. sizes the fuel-consumption has been taken as 6½

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gal. per hr. for the Diesel, 9 gal. per hr. for the hot-bulb engine and 10 gal. per hr. for the gas engine. The fuel-consumption has been increased somewhat for the smaller sizes and decreased slightly for the larger sizes It varies with the mechanical condition of the engines and the care of the operator much more in the case of the gas engine than in the hot-bulb, and the hot-bulb is more sensitive than the Diesel, but these consumptions have been taken as representing good average conditions with care upon the part of the operator. A poorer consumption on the part of the other engines will only make the case more favorable for the Diesel engine. The prices of fuel

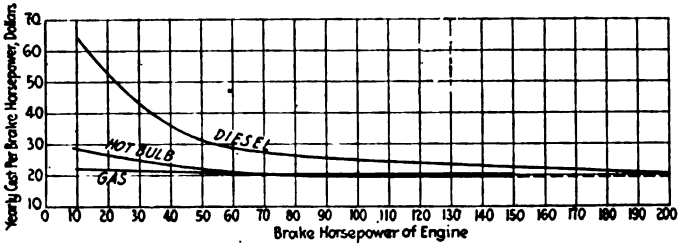

FIG. 1—CHART SHOWING THE COMPARATIVE OPERATING COSTS OF DIESEL, HOT-BULB AND GAS ENGINES BASED UPON 250-HR. YEARLY OPERATION

have been assumed as 10 cents per gal. for the Diesel and hot-bulb engines, and 26 cents per gal, for gasoline for the gas engine. These are less than the present-day retail prices along this section of the Atlantic coast, but the price ratio will remain about the same in any case and the shape and relative positions of the curves will not be changed.

Fig. 1 is a chart representing 250 hr. of operation per annum, which is about the average for a yacht, Fig. 2 represents 1500 hr. of operation per annum, which is about the average for a work boat in a seasonal trade, and Fig. 3 is for 3000 hr. of operation per annum, which covers approximately the case of the boat which is used the year round. An inspection of these charts will show at a glance that the gas engine is out of the running entirely except in the case of the yacht; that is to say, in spite of its low first cost, the high cost of fuel brings up the cost of operation so that within the limits of sizes under discussion it is almost never economical to install a gas engine. The boat owner simply cannot afford to

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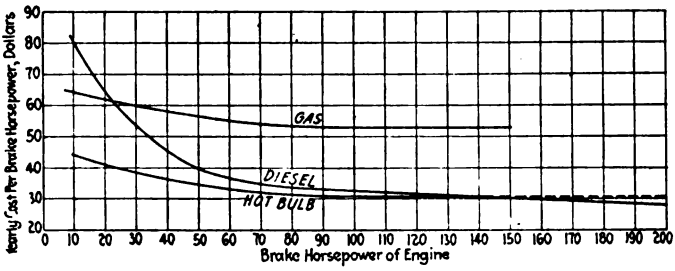

FIG. 2—CHART SHOWING THE OPERATING COST FOR VARIOUS TYPES OF INTERNAL-COMBUSTION ENGINE BASED ON AN ANNUAL OPERATING TIME OF 1500 HR.

install a gas engine in any size where the oil engine is available.

There is another very important item in this connection which is not shown in the charts but should be brought out at this time, and that is the question of insurance. Most of these small commercial work boats are of wooden construction, and the insurance rates are high enough in any case, but with a gas engine and the presence of gasoline in large quantities with the attendant danger of fire, the insurance companies demand a higher rate of insurance than they do in the case of the oil-engined vessel. This omits, of course, the question of safety of the crew, but in a seagoing vessel this must not be ignored, and makes the case all the stronger for the oil engine. Both the hot-bulb and Diesel types of engine use a fuel of high enough flash-point so that there is practically no danger of fire due to the presence of the fuel itself even with the most ordinary precautions. The hot-bulb engine has a slightly increased fire risk as com-

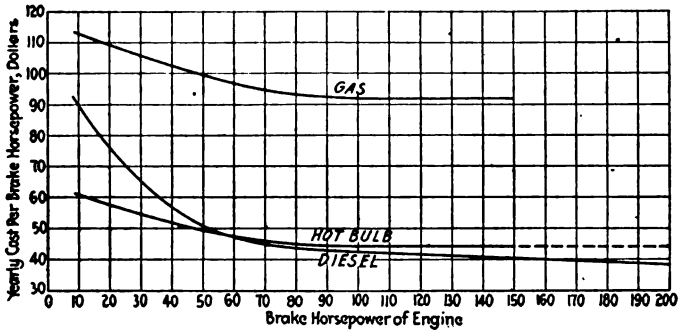

FIG. 3—OPERATING COST OF AN ENGINE IN A VESSEL WHICH IS IN SERVICE FOR 3000 HR. ANNUALLY OR PRACTICALLY THE ENTIRE YEAR

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pared with the Diesel engine on account of the use of open flames for heating the bulbs when preparing for a start, but this is not a serious risk even for these engines, and in some forms of hot-bulb engine, and all types of the Diesel engine, this is eliminated entirely. The question, then, comes down to a choice of a Diesel or hot-bulb engine.

Fuel and Lubricant Economy

The charts show that for 250 hr. or less yearly operation the Diesel engine cannot overcome the handicap of a large initial first cost with its superior fuel economy; for 1500-hr. operation per year there is very little to choose for 100-hp. sizes and over, but as the number of hours of operation increases to 3000 the superior oil economy of the Diesel engine asserts itself and the Diesel engine has a decided advantage.

The curves do not show all of the advantages of the Diesel engine. As a matter of fact, the Diesel engine can use a wider variety of fuel than the hot-bulb engine, and more important, can use fuels of a heavier grade. With the present fuel situation, this is a factor that must not be overlooked because the present fuel outlook indicates that heavier grades of fuel will be more readily available in the future than the lighter grades, and with a Diesel engine installed the boat owner need not worry about the future in this respect; while with the hot-bulb engine there seems to be a possibility that in the future there may be such a scarcity of the lighter grades of fuel oil as to force the price upward. Another important point is the mechanical operation of the two types of engine in the various sizes. In sizes up to, roughly, 100 hp., the hot-bulb engine is reported in a great many cases to have given eminent satisfaction as regards operation, but there are several cases on record in the larger sizes where the owners have had many difficulties. On the other hand, the Diesel engine while functioning perfectly in the small sizes is very expensive to build relatively, and does not show a marked superiority in cost of operation over the hot-bulb engine. When it comes to sizes of 100 hp. and over, the superior mechanical performance of the Diesel engine and its advantage in cost of operation become more marked, and the larger the size of the engine the more advantage the Diesel engine has in these two respects. Along this line it is to be noted that certain makes of hot-bulb engine have added a small air-compressor and changed the cycle of

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operation to more nearly that of a Diesel engine in the larger sizes.

The consumption of lubricating oil has not been figured into these curves, and it has been taken as the same for all of the types of engine of a given size. This is approximately true in considering the best types of hot-bulb engines working under the best of conditions, but since most engines of this type have crankcase compression and port scavenging of the working cylinder, the consumption of lubricating oil is likely to be very high

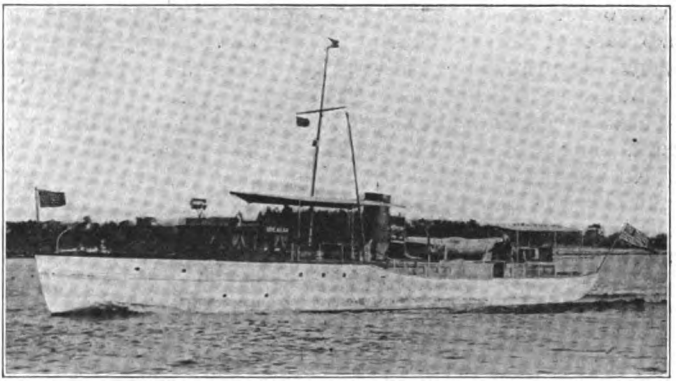

FIG. 4—A YACHT EQUIPPED WITH A 120-HP. DIESEL ENGINE

unless the design of the engine provides for this contingency with special mechanical features which prevent undue leakage of oil from the bearings into the crankcase, and even with these added features they must be kept in the best mechanical condition. This means that the Diesel engine has as good a lubricating-oil consumption as the hot-bulb engines under the best conditions, and under the worst conditions the Diesel engine has a decided advantage. In this connection it can be stated that a fair lubricating-oil consumption for a Diesel engine is from one-fiftieth to one-seventy-fifth of the fuel-oil consumption at full power.

The question of attendance is another item that has not been included, but this is more or less a constant for all sizes and types of engine under consideration. In boats of this type it is customary to carry only one engineer except in the case of large powers where the operation involves 24 hr. per day running. In the case

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of fishing schooners which have 100-hp. and even in some that have 180-hp. engines installed it is customary to carry only one engineer even though non-stop runs of 80 hr. are very common. Under these circumstances the engine has to take care of itself for periods of 4 and 5 hr. at a time while the engineer sleeps. This practice is, of course, not to be recommended, but these are the actual conditions obtaining, and show the reliability and simplicity of powerplants of this type. In the case of small harbor boats, it is customary to have the engines controlled from the pilot house, and oftentimes in this case the entire crew consists of a captain and deckhand. Where 200 hp. or more is installed, and particularly in the case of vessels depending upon their engine power alone for propulsion, several engineers are carried; but in any case the number of men carried and the cost of operation depend upon the size of the powerplant and conditions of operation rather than upon the type.

No marine powerplant can be considered which is not reliable. In fact, several other shortcomings can be tolerated but unreliability cannot. The question of fire risk has already been discussed and the advantage of the oil engine shown. As for mechanical operation there is little choice as with a properly designed and installed engine, any one of the three types under discussion is thoroughly reliable as is daily attested by the large number of boats in operation which depend entirely upon these engines for their propulsion.

Mechanical Reversing Gears

It has been shown that the Diesel engine has a field almost to itself in sizes above 100 hp., and even today as young as the industry is the type of engine most suitable for this class of work has been very thoroughly proved. It will be found that the Diesel engine almost universally used in these sizes is of the four-cycle type. This is because of the greater simplicity as compared with the two-cycle type. In this size of four-cycle it is not necessary to cool the working pistons; hence all complications inside of the crankcase are omitted. Also a mechanical reversing gear is cheaper and has many operating advantages over a directly reversible engine. This means that the number of cylinders and mechanical arrangement on the engine are not primarily dependent upon the requirements for reversibility, but can be chosen to best suit other conditions. Therefore it is found that

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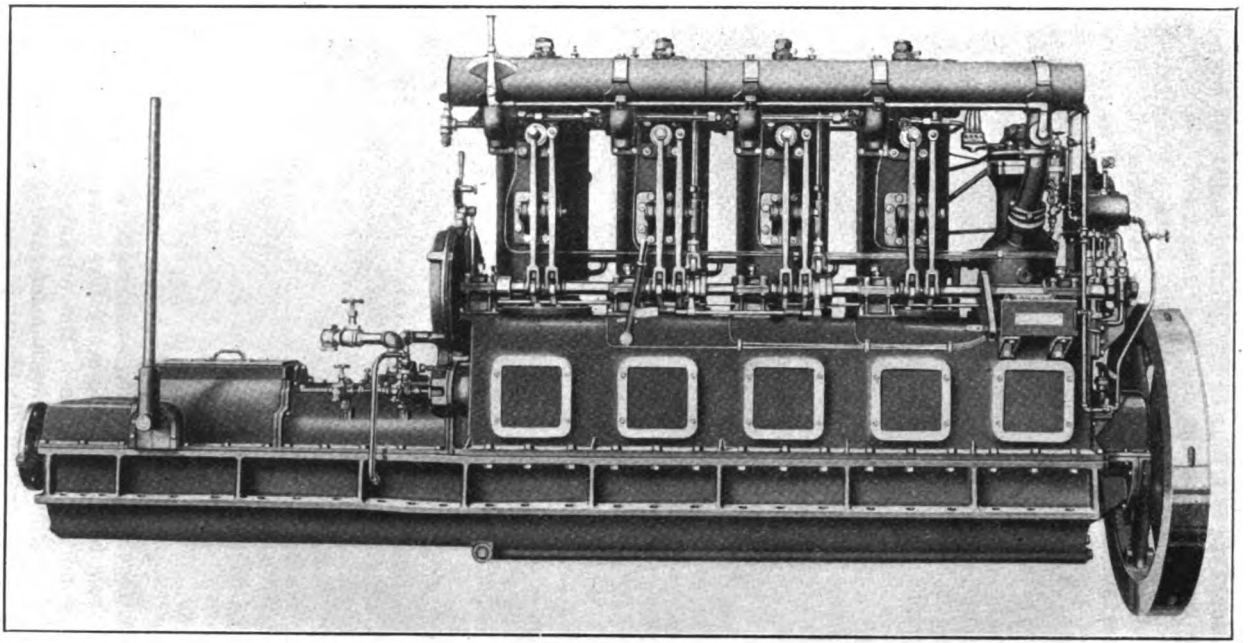

FIG. 5—A FOUR-CYCLE FOUR-CYLINDER DIESEL MARINE ENGINE DEVELOPING 120 B. HP. AT 350 R.P.M. WHICH IS EQUIPPED WITH A REVERSING CLUTCH AND THRUST BEARING FITTED ON AN EXTENSION OF THE BEDPLATE

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the usual type is a four or six-cylinder, four-cycle engine made reversible by the use of a mechanical gear. The four-cycle engine is also slightly more economical as regards fuel consumption than the two-cycle, and there are certain other mechanical advantages, such as reversing of pressure on the bearings and easier heat conditions in the working cylinders which make the four-cycle look so attractive.

The question of where to begin to build directly reversible engines and leave off the mechanical reversing gears is one that depends upon many factors. With a directly reversible engine a minimum of six cylinders is required to provide for reversibility under all positions of the crank; whereas if a mechanical reversing gear is fitted, a four-cylinder engine can be used which will provide larger cylinders and a lower number of revolutions per minute for a given horsepower. This is an advantage in marine work as it provides a more efficient propulsion with a reduced number of revolutions, and this is advantageous from the mechanical standpoint where hard continuous service is expected over long periods. The weight and cost are, of course, slightly increased as compared with a six-cylinder engine; but the other advantages outweigh this disadvantage. If considerable maneuvering is to be done, the mechanical reversing gear has a decided advantage, because no matter how many maneuvers are executed or how fast the signals come from the pilot house, every signal can be answered without using compressed air; and compressed air in large quantities for maneuvering engines is very expensive. Of course even on the non-reversible engine with the mechanical reversing gear the engines are started by compressed air, but the amount of air-flask capacity required is very much reduced, and very simple provisions can be made for renewing this supply; whereas in the case of a directly reversible engine the question of refilling the starting flasks is an important one, and in some cases would require the supplying of a separate auxiliary compressor unit for this purpose alone. When it is considered that in the case of tugboats and some fishing vessels 5 or 6 hr. continuous maneuvering with a signal from the pilot house every few minutes or oftener is the condition to be met, the advantages of a non-reversible engine with a mechanical reversing clutch are evident. The question of obtaining a reliable mechanical reversing clutch is very important. There are many

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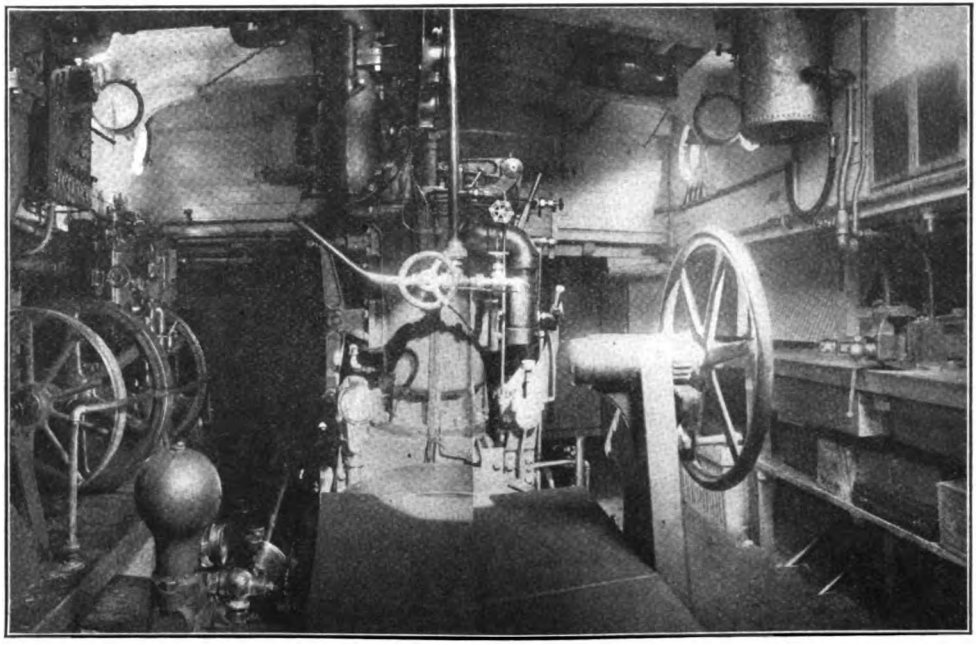

FIG. 6—THE ENGINE ROOM OF A CANNERY TENDER EQUIPPED WITH A DIESEL ENGINE

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gears on the market for the smaller sizes say up to 100 hp., but in powers larger than this there are very few firms in a position to supply a clutch powerful enough to withstand the severe usage given it under the circumstances just mentioned, and in many cases the engine builder is driven to designing and building his own clutch especially for his engine. The point is soon reached in size, however, where the mechanical reversing clutch becomes extremely large, heavy and costly, and then in spite of its advantages from the operating standpoint, it is necessary to get back to a directly reversible engine. There is, of course, no definite line of demarcation, but it is considered that somewhere in the vicinity of 300 hp. it is generally cheaper to build a directly reversible engine than it is to build a mechanical reversing clutch which will be stout enough to stand up with the engine.

The Electric Drive and the Steam Engine

There is another solution to the problem of reversing the propeller in a motor boat and that is the electric drive. In this case a non-reversible engine or engines drive generators and run at a constant speed. On the propeller there is a motor which receives its power from the generators and its speed and direction of rotation are controlled by electrical means. This type of installation has several advantages, particularly for some special cases like fishing trawlers, tugboats and fire-boats. In the first place it is usual to provide at least two engines even for a single-screw boat. This gives added reliability, reduces the first cost because smaller engines are used than in the case where one engine alone is used, there is extreme flexibility and the controlling of the boat from the pilot house is a very simple matter. A very important feature, however, is that in case the boat is slowed down the motor only takes the overload and the engines and generators run at regular power and speed. This particular phase is important for tugboats and fishing trawlers where for a very large portion of the time the speed of the boat is slowed down due to resistance of the tow or of the trawl, but full power is desired from the propelling machinery. In the case of direct-connected engines under these circumstances the revolutions of the propeller are, of course, decreased, which in turn decreases the power output available from the engines. The advantage in the case of a fire-boat is in the great flexibility of control and operation; that is the engine would drive the gener-

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ators at constant speed and power could be taken as required for the motors, for propulsion and the motor-driven fire pumps.

As has already been mentioned, the Diesel engine in the larger sizes of several hundred horsepower for commercial work boats has for its principal competitor the steam engine. One particular phase of this competition is in the case of the fishing trawler. These vessels have long

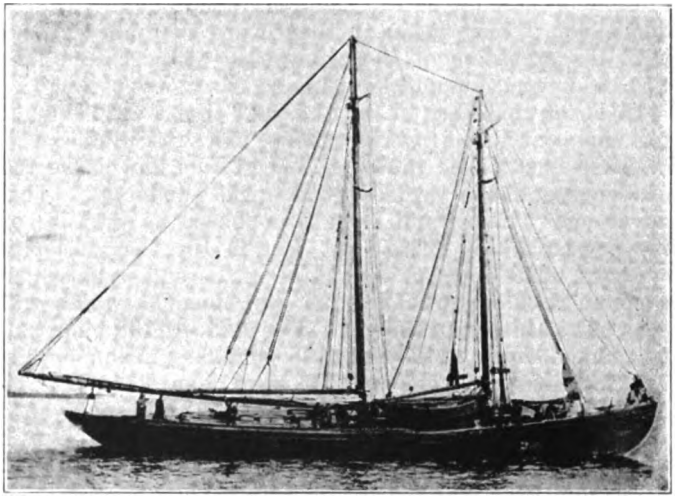

FIG. 7—A TYPICAL EXAMPLE OF A FISHING SCHOONER DRIVEN BY A DIESEL ENGINE

runs from their home ports to the fishing banks and hence require considerable amounts of fuel to take them to the fishing banks and back, to say nothing of that consumed while trawling on the banks. These boats are of course only of moderate sizes and the question of radius of action is very important. In the case of steam trawlers it actually requires an increase in the size of the boat in order to be able to carry coal enough for the round trip, and even then some of the banks in the North Atlantic which are fished from New England ports are so far away that the steam trawlers cannot carry fuel enough to make the trip. In the case of the Diesel engine matters are entirely different. The company which I represent has made two installations in boats of this character. Both of them are about 150 ft. long and carry approximately 300,000 lb. of fish. One boat has a 360-hp.

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directly reversible engine and the other has two 240-hp. engines with the electric drive. A speed of approximately 10 knots is obtained and these boats have a cruising radius at full speed of about 6000 nautical miles and at three-quarters speed of about 9000 nautical miles. This is more than sufficient to take them to the farthermost fishing banks and back. In other words, in this particular field the Diesel engine has no competitor and while these faraway banks are not fished very much at present on account of the plentiful supply of fish nearer home, yet it may mean in the future that all trawlers with the exception of those propelled by Diesel engines will be driven out of the business.

In conclusion then it can be said that for yachts or for any boat which operates very little, the first cost is of more importance than the cost of fuel and hence the gas engine has a decided economical advantage. This advantage is more and more pronounced as the size of the powerplant is decreased. But in the vast majority of cases, some form of oil engine is the only type which a commercial motorboat owner can consider which will meet all of his requirements. For sizes of 100 b.hp. and less, some form of hot-bulb or surface-ignition engine has the field to itself, but for sizes above 100 hp. the Diesel engine shows its superiority more and more until for 200 or 300 hp. and more, it, in turn, has the field almost entirely to itself. The ordinary tugboat, passenger boat and fishing boat uses the Diesel engine because of its economy, and the fire-boat will use the Diesel engine because of its absence of standby losses. Reliability, simplicity and ease of attendance are essential in all cases, and the present-day Diesel engine is fully up to the requirements.

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THE GERMAN SUBMARINE DIESEL ENGINE

By Lieut-Com Holbrook C Gibson[1] U S N

The author describes the type, size and general characteristics of the engines with which the German submarines were equipped at the time of the surrender, after having personally inspected 183 of them at that time, and then presents the general details of construction of these engines, inclusive of comments thereon.

The maneuvering gear for such engines receives lengthy consideration and the reliability of engines of this type is commented upon in some detail, the author having confirmed his opinion that the German submarine engine is extremely reliable.

One of the controlling factors in the design is that the Germans had investigated steel casting to the point where the successful production of steel castings was an ordinary process, and the author believes this to have been largely responsible for the success of the German submarine engine.

Much to the surprise of everyone present at the time of surrender, the German submarines came up to their moorings, maneuvering entirely by using their engines. This performance caused much favorable comment. An inspection was made of the various boats and in the majority of cases it was found that the engines were of Machinenfabrik-Ausburg Nürnburg (M.A.N.) four-cycle reversible type. A few other types were found, such as the Vulcan, Bolhm-Voss, Koerting, Benz, Nürnburg two-cycle and Krupp two-cycle but, comparatively speaking, they were very few in number. In our own submarine service, before the war we had heard much about the Krupp two-cycle engine and naturally supposed that this was the best engine in Germany. However, the Krupp interests were so powerful at that time that they had had their engines adopted for the German submarine service. Out of about 183 submarines which I personally inspected at the time of the surrender, there were only five or six boats that had Krupp engines and they were out of repair. These engines also had one serious objection in that the cylinder-heads and some other parts were made of bronze, which metal became very scarce during the war. As soon as the war was well

[1]Submarine Repair Base, League Island Navy Yard, Philadelphia.

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under way, the German authorities had to listen to the operating personnel and it became necessary to adopt the M.A.N. four-cycle engine, which can be considered as the standard for the German submarine. However, this type of engine was not a war product, but was a practical proposition as far back as 1912.

During our inspection we found one submarine which was fitted with a pair of M.A.N. four-cycle 800-hp. engines dated 1912. It was about that time that one of our own submarine officers was in Germany. He was shown practically everything in the Ausburg shops except a certain four-cycle engine which was in an enclosure undergoing shop tests. I have reason to believe that this was the engine type which was later adopted for the German submarine service, but it was not until after the war that this four-cycle engine became generally known. Nothing much was heard of it and what one did hear was very vague. Inspections of the German submarine flotilla and various submarine engines and engine plants in Germany revealed that the M.A.N. four-cycle engine predominated. It was being built not only by the Ausburg plant of the M.A.N. company, but at all the other engine plants. The M.A.N. engine is built in the following sizes: 100 hp. at 550 r.p.m.; 300 hp. at 550 r.p.m.; 500 hp. at 500 r.p.m.; 1200 hp. at 450 r.p.m.; 1750 hp. at 380 r.p.m.; and 3000 hp. at 390 r.p.m. The fundamental design of all these engines is the same, but as the size increases certain modifications are necessary. The bedplates are all of cast steel and so are the cylinder jackets. The cylinder-heads and pistons are of the usual material, close-grained cast iron. The crankshafts and connecting-rods are of good quality steel. The M.A.N. engine, with the exception of the 3000-hp. size, is made with six cylinders and an air compressor on the forward end which also carries the fuel pump and a device called the spray air regulator. Everything that is needed to run the engine is located at the forward end, available for the operator.

Regarding the 100-hp. engine, it happened that I went around Kiel harbor in the barge of one of the former German admirals. I noticed that the boat had a quick getaway and high speed. I looked into the engine room and saw that it had a 100-hp. M.A.N. Diesel engine just like the larger ones. This size is a practical proposition; it operated beautifully. This little engine had six cylinders and one three-stage air-compressor on the forward

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end. The engine was air-starting and had a mechanical reversing-gear through the clutch.

The 300-hp. type of engine had the same general design characteristics as the 100-hp. size. The pistons of the 100 and the 300-hp. engines are not cooled. The 500-hp. size has six cylinders also and has additional features such as air-starting and reversing and two spray valves in each cylinder-head. In other words, it has a twin spray valve for fuel admission. The pistons are oil-cooled in this size.

The unit developing 1200 hp. at 450 r.p.m. is exactly the same as the 500-hp. size; it has oil-cooled pistons and some variations in the type of air compressor. There seems to be no standard practice regarding the use of a three or a four-stage air compressor. In a mine-laying cruiser one will find a four-stage air compressor and in another type of boat a three-stage compressor. In the former the compressor is used not only for the engine but for charging the air supply for the ship. That is the only difference in the 1200-hp. type. They are all the same and look as though they had been cut from the same pattern. The 1200-hp. engine can be considered as the German standard, since it was used in a great many vessels; their 800-ton submarine was the standard submarine. A German officer told me that if Germany had con-

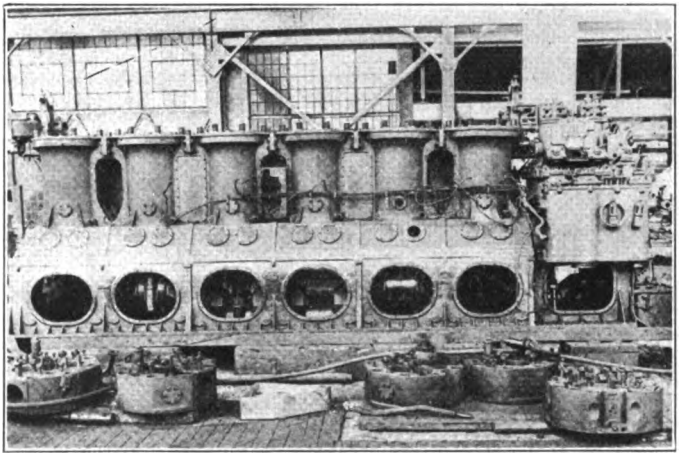

FIG. 1—SIDE VIEW OF A 1200-HP. DIESEL ENGINE SHOWING THE STEEL CONSTRUCTION OF THE BEDPLATE AND THE HOUSING WHICH ARE INTEGRAL UP TO THE BASE OF THE CYLINDER JACKET

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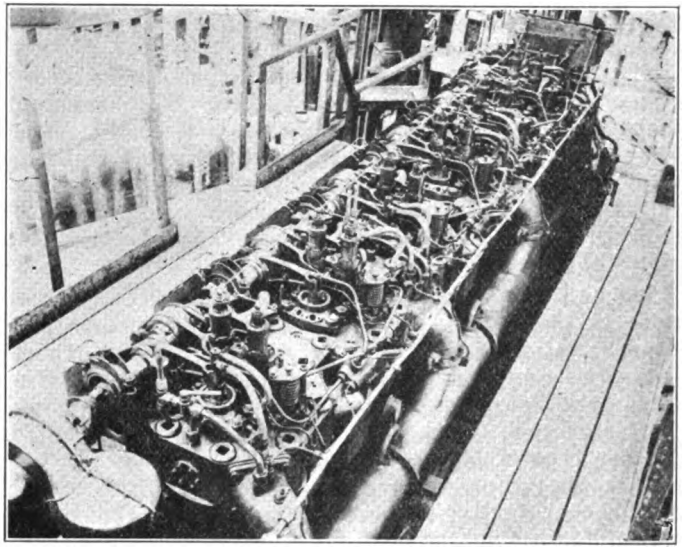

FIG. 2—LOOKING DOWN ON THE 1200-HP. ENGINE

centrated on this 800-ton submarine type, Germany would have won the war. I do not know the total number, but they built 200 or 300 of the 800-ton boats and each was equipped with the 1200-hp. engine.

GENERAL DETAILS OF CONSTRUCTION

Fig. 1 gives a very good idea of the steel construction of a 1200-hp. engine. The bedplate and the housing are integral up to the base of the cylinder jacket. The bedplates are made in sections to take in two cylinders and they are bolted together with many bolts, resulting in a very substantial construction. The joints can be seen in the illustration. There is a small section on the forward end for the air compressor. The cylinder jackets are also bolted to one another and go all the way across on the inside, forming a regular girder construction; the result is a very rigid engine but, where it is bolted together, it is free to expand upward. In other words, the bolts that go through the section are not fitted but are loose, the cylinder jackets being able to expand upward.

Fig. 2 shows the engine viewed from above. The principal feature to be noted is the twin spray valve. In my opinion the idea of the twin spray valve was originated on account of the construction of the cylinder-head. If

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they had cut one big hole in the cylinder-head for the spray valve in addition to the large inlet-valve opening, the cylinder-head would have been materially weakened. It looks complicated, but really is not and it works beautifully. The satisfactory operation is simply a matter of accurate workmanship and proper lining up of the valves.

Fig. 3 gives an idea of the mechanism at the forward end. This is the 1750-hp. engine, but it is practically the same except for one additional feature. The fuel pump, air regulator and air compressor are shown. There are three air-coolers and below the coolers are the three separators for the various stages of the air compressor. The wheel shown controls the reversing mechanism which is on the 1200-hp. engine and smaller sizes. It works very easily and one man can handle it without any trouble. This 1750-hp. is the type of engine discovered on the so-called Von Tirpitz super-submarine. These vessels run from 2000 to 2700 tons displacement and were

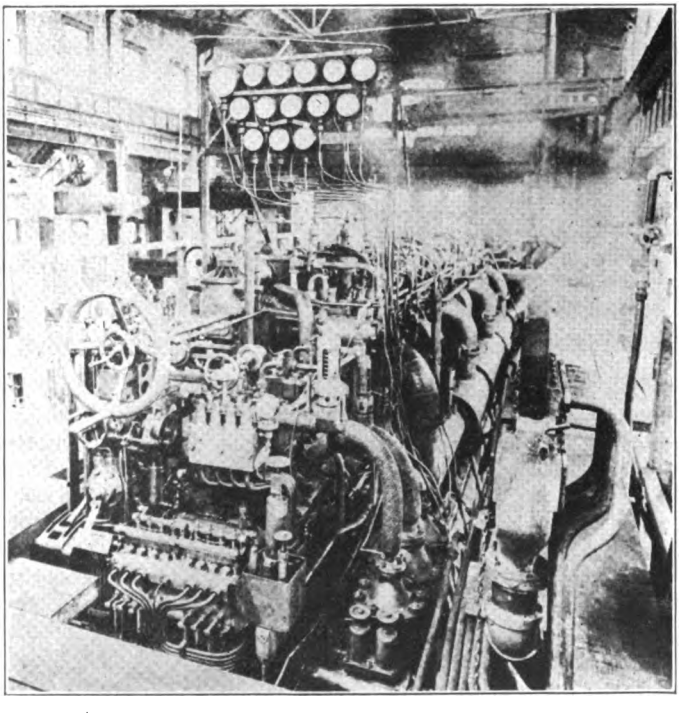

FIG. 3—LOOKING AT THE FORWARD END OF THE 1750-HP. ENGINE

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built primarily to operate on the Atlantic Coast of the United States. The engine in the 2000-ton boat is of the 1750-hp. type. As is seen in Fig. 3, it has six cylinders, with air-starting and reversing gear. It has all the earmarks of its predecessors except a few radical departures in design.

Fig. 4 shows the 3000-hp. engine found on the 2700-ton boats which were the largest of the German submarines. It is practically the same as the 1750-hp. engine except that it has 10 cylinders instead of 6. The picture of an average man standing alongside gives an idea of the size of this engine. All of the German engines are

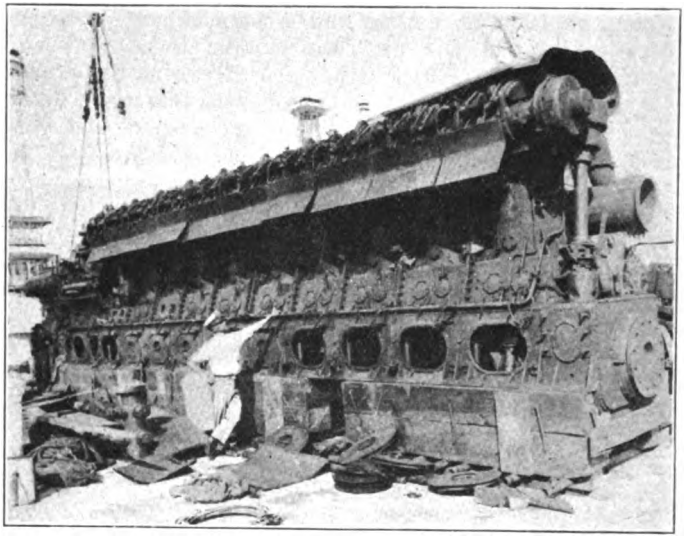

FIG. 4—VIEW OF THE 3000-HP. ENGINE WHICH WEIGHS 14,000 LB.

comparatively light for their horsepower. The 1200-hp. engine, complete with exhaust heads, dependent auxiliaries and everything except miscellaneous piping and the oil cooler, weighs 57,000 lb. The 1750-hp. engine, complete with dependent auxiliaries, flywheel, exhaust heads and the like, weighs exactly 97,530 lb. The 3000-hp. engine weighs 72 net tons, or 144,000 lb. One can see in the illustration how the engine is bolted together; all the bolts fit loosely so that the castings are free to expand upwards, but not fore and aft.

Some radical departures are made in the construction of the pistons of the 1750-hp. engine. Fig. 5 shows the six pistons removed. From a casual glance one would

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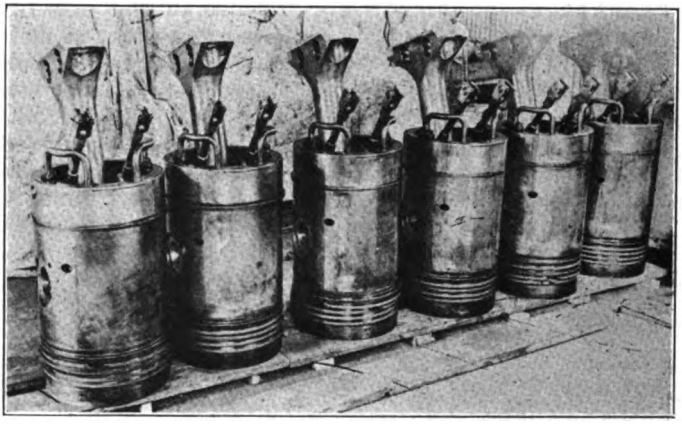

FIG. 5—THE PISTONS OF THE 1750-HP. ENGINE REMOVED

think they were exactly the same as those of the 1200-hp. engine. However, when we commenced to clean them up and looked on the inside, we noticed a row of bolts. When these were taken out we discovered that they released the piston-head. The pistons are a radical departure in design from their predecessors in other engines. Fig. 6 shows one of them taken apart; the trunk of the piston, with the flange at the top; the piston-head, looking inside; and the cover that goes up inside of the piston to make it a closed cavity so that the oil cannot escape. The piston-head is a very fine piece of work. It is a block of semi-steel, machined inside and out. The cavities are for the cooling oil which comes in at the side, works its way around through these grooves and finally into the

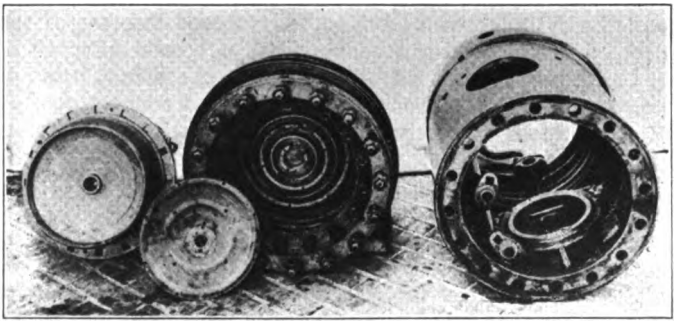

FIG. 6—ONE OF THE DIESEL ENGINE PISTONS TAKEN APART

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center and out. Locknuts are provided so that it is impossible for the inside cover-plate to get adrift. A plate goes on over the oil grooves. Some of the groove walls are made thicker than others to provide for the screws which hold the cover-plate on. The bolts that hold the piston-head to the flange of the piston are riveted through and they are all locked with lock-pins and locknuts so that the whole is a unit and cannot come adrift. This design of piston is one of the important departures from former practice. To my mind, it is the most interesting. The cooling-oil pipes are shown which carry the oil in at the periphery and out at the center. The Germans apparently were experimenting more or less with this type of piston, for we discovered that the pistons in the engines of the submarine U-140 were slightly different from those of the U-127, although the engine was exactly the same to all appearances. The pistons described were taken from the engine of the U-127 and are apparently of later design.

Another interesting feature about the piston is that on the former engines the pistons were straight from the bottom of the working rings to the bottom of the piston. On this type of piston we found that the skirt was relieved all the way down for a space about 6 in. wide and parallel to the wrist-pin ends. The diameter of the piston is 21 in.

Fig. 7 shows the construction of the connecting-rod and the wrist-pin bearings which is the same throughout all the engines that have cooled pistons. It shows how they provide additional bearing area for the wrist-pin bearings which are subjected to much heat and heavy pressure. The Germans apparently had no trouble with these bearings, for we have had cases where the piston and the cylinder wall have actually scored because of the dirt, and the wrist-pin bearing has not been affected in the slightest degree. A steel forging or casting, I do not know which, goes through the eye of the connecting-rod. It is made in two halves. The upper half of the wrist-pin bearing is shown partly taken out. The lower half has lips or projections to hold the shell in place. The upper half has one small lip and is slipped in last. The wrist-pin bearing is made the extreme width that can be obtained from the inside of the piston; almost double the width of the eye of the connecting-rod is obtained. Naturally, the wrist-pin pressures are very much reduced in this way. The bearing metal, instead of being

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a bronze bushing, is of comparatively thin babbit metal. They have a fitted distance-piece, measured by micrometers, between the upper half of the bearing and the eye of the connecting-rod. The connecting-rod is drilled out to make it light and when oil is forced to the wrist-pin, this big hole or cavity fills with oil; the inertia of this oil column tends to pull the oil from the wrist-pin and run that part dry. Instead of putting in a check-valve at the foot of the connecting-rod to prevent this, they

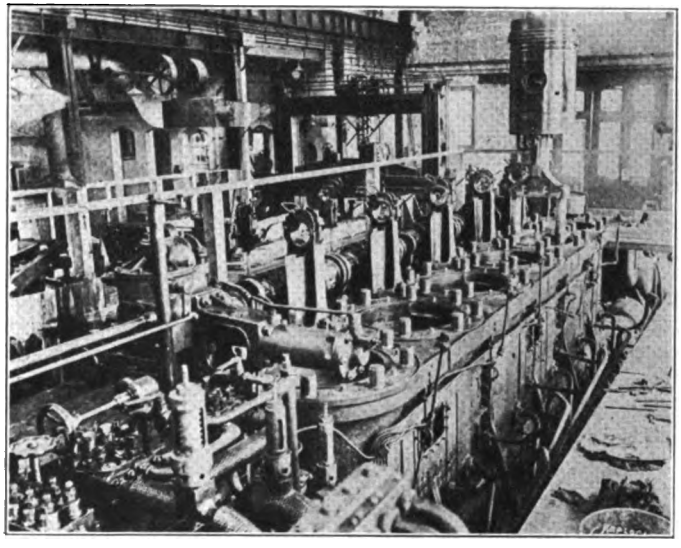

FIG. 7—THE CONSTRUCTION OF THE CONNECTING-ROD AND THE WRIST-PIN BEARINGS WHICH IS THE SAME FOR ALL ENGINES HAVING COOLED PISTONS

have put in a pipe with a screw plate and screwed the pipe into the wrist-pin bearing. The connecting-rod is not filled up with oil and they do not have the difficulty that we sometimes encounter. It is a very simple scheme and there is nothing to go wrong. Another interesting feature in this engine is that the after bearing is of a larger size than the other main bearings of the engine. This bearing is 12.375 in. in diameter; the other bearings are 11.223 in. in diameter. This is done to provide support for the clutch.

MANEUVERING GEAR

Fig. 8 shows an engine having the same maneuvering gear as the 1200-hp. engine; it has the same handwheel

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for operating the valve gear. This wheel works through a series of bellcranks and levers and raises the valves clear of the camshaft; the camshaft moves sufficiently to bring another set of cams in line and, to complete the operation, the valve gear is lowered on the new set of cams. On the 1200-hp. engine this was done manually and, while it could be operated readily by the average man, it was a hard task to do this several times per minute in answering the engine-room signals. On the 1750-hp. engine this reversing gear can be operated in this way, but it is really all that one very strong man can do; so, in addition to the manually operated gear, a gear is installed which operates by air and also by oil. It is a small box that has four valves in it and by turning a small handwheel in one direction the proper valves are depressed admitting air to a ram. There is an interlocking device on the front of the engine so that when the power-operated maneuvering gear is used the hand gear is thrown out. It is interlocked. When this handwheel is turned, the ram goes over in about 2 sec. and the engine is then ready to operate in the other direction. In case the air pressure fails, there is a small oil-pump provided and the ram can be pumped over with oil pressure. The operating gear shown had not been used in two years and we tried it today to see if it would work, as it was the only thing on the engine that we did not take apart. We found that it operated very satisfactorily, as if it were put together only yesterday. Another interesting feature on this type of engine, which is simple but apparently very necessary, is a stop-valve on the circulating water supply which is operated by the starting levers of the main engine. It is a sluice valve in the header which supplies water for the working cylinder jackets. It is arranged so that when the operating levers are brought to the stop position the water is cut off from the working cylinders, and it is impossible to supply water to them until the engine is started again. From reading a confidential German instruction pamphlet, I noticed that they lay stress on the fact that cold water must not be put into the engine when it is shut down. The water must be turned off the minute the engine stops. But with this engine, even when using independent electric auxiliaries, it is impossible to damage the engine by pumping cold water into it after the gear has been brought to the stop position. That is a refinement and I suppose it is very necessary. I am also

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of the opinion that this may have something to do with the air-starting of the engine. In other words, it is not possible to put water on the working cylinders until after the engine has started firing. Consequently, when starting with air, the cylinders are not being cooled with cold water.

One other point in the operating gear that does not appear in the older engines is interesting. There are three indicators on the dial of the operating gear, marked *Voraus, Tachstellung,* and *Zurick.* The *Voraus* and *Zurick* mean ahead and astern, and *Tachstellung* means

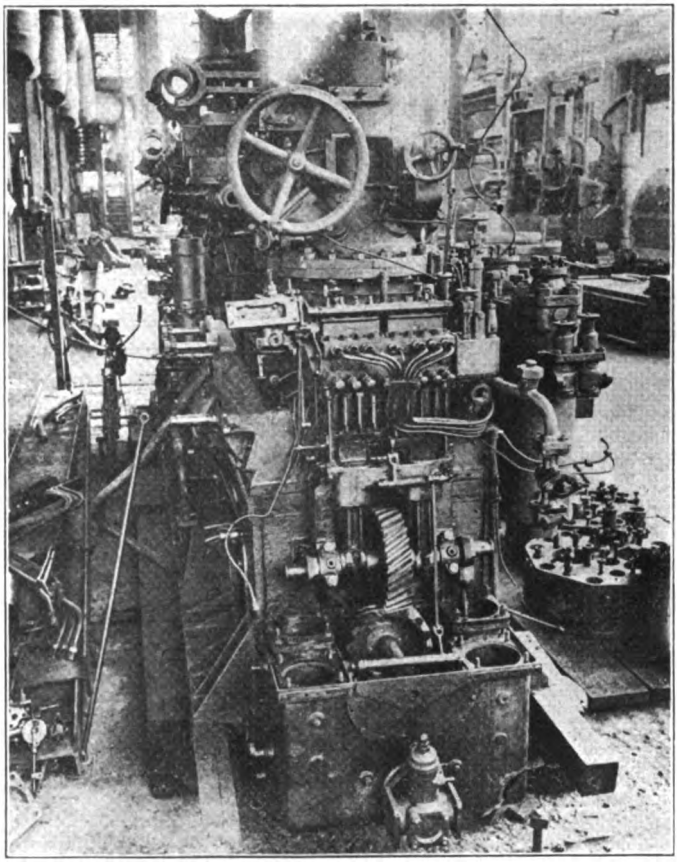

FIG. 8—THE MANEUVERING GEAR OF THE 1750-HP. ENGINE WHICH IS TYPICAL OF ALL THE GERMAN SUBMARINE ENGINES

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diving position. I have been trying to discover a real reason for this third setting and, so far as I can determine, the diving position means the position in which the engine control is placed when the boat dives. It is just the same as the neutral position of the engine, midway between ahead and astern. I think it is one of the refinements that was developed during the war. In case a submarine comes to the surface, the commanding officer is able to maneuver the ship to the best possible advantage. It might also be used in an emergency case, to avoid ramming. If the commanding officer had the controls in the *Tachstellung* position, he would then be in the best possible maneuvering position for any emergency that might arise.

Fig. 9 shows the oil-pump. One of the great troubles we have had in our own service is to build a good lubricating oil-pump. I do not necessarily mean a pump that never breaks down, but sometimes oil-pumps make too much noise. This pump is the same kind that is used on all the German engines. It is very simple and consists of two gears, one of which is fitted with a cylinder with grooves cut in it. So far as I can make out, the idea is that in an ordinary gear pump a certain amount of oil is trapped between the teeth after the oil has been discharged, creating a tremendous pressure which naturally makes it pound. The pump shown is designed so that, when the teeth are in a certain position after the oil has been delivered and a certain amount of oil has been trapped, the holes come into position and the oil passes through the groove. This pump is very smooth-running and is almost noiseless. I took one apart on a 1200-hp. engine which had been operating for 25,000 miles, but the original toolmarks were still on it and all we did was to put it together again. It is apparently a very satisfactory design of pump and very efficient.

Fig. 10 shows the main engine clutch on a German submarine. It is necessary to have a clutch between the main engines and the electric motors so that when the boat dives the engines can be disconnected. This clutch is typical of the German design and is very simple. It consists of two truncated cones. The cones slide on a spider, operated by springs. There is a sleeve on the end, with bellcranks to force the truncated cones in and out against the outside casing. The travel is very small, only ½ in. The angle of the cones is 28 deg. The cones are made of cast iron and the outer rings are steel. They

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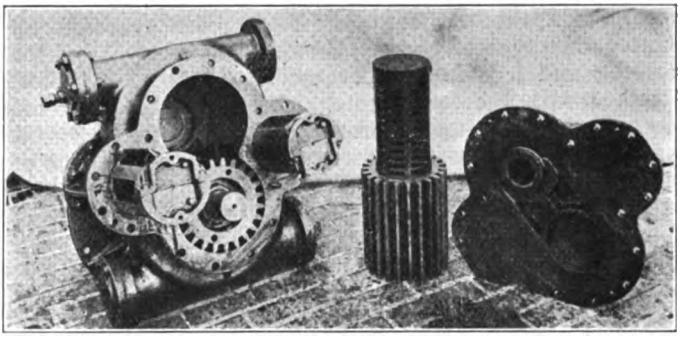

FIG. 9—THE OIL-PUMP DISASSEMBLED INTO ITS VARIOUS PARTS

are forced in and out by means of a pneumatic piston which is controlled by a small valve. This control enables extremely rapid engagement and withdrawal of the clutch.

RELIABILITY

I have confirmed my opinion that the German submarine engine is extremely reliable. Some thorough tests were made on a 1200-hp. engine without any trouble or breakage. This was an old engine which had been horribly abused. It was overhauled, put in operation, and ran without much trouble. A former German submarine, the U-111, was operating last winter with some of our submarines. It had a green crew and none of them knew

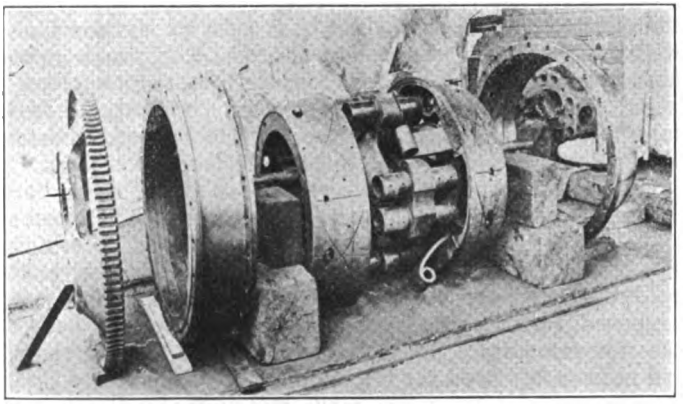

FIG. 10—THE MAIN CLUTCH OF THE DIESEL SUBMARINE ENGINE

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anything about the engine. The vessel operated all winter until it came to the League Island Navy Yard for docking and painting preparatory to some speed trials. I talked with the commanding officer, and told him his engine was not adjusted properly, but in spite of this it was running very well and was misleading on account of such satisfactory operation. I persuaded him to allow the gang of men I had used on previous engine tests to tune the engine up for him. It was found that everything possible on the engine was wrong; it was all out of adjustment. The gang cleaned the engine parts, set the valves, ground them in tight and set the parts according to the data we had collected on this 1200-hp. engine on test. The vessel went out burning up its fuel perfectly. She developed over 17 knots, while on the previous trial she could not make 14 knots. This demonstrates that the German submarine engine is reliable and can run even if the personnel are not highly trained. That is a condition we must meet in submarine service.

The submarine Diesel engine is not an ordinary Diesel engine, mainly because the requirements are so exacting. The submarine demands everything of an engine that is difficult to get. The space and the weight are limited; the service and treatment are very severe. The requirements of a submarine Diesel engine might be considered as a quest of the absolute. It must be entirely free from imperfections both in design and workmanship. The Germans spared nothing on the submarine campaign to win the war, and I think the results have shown themselves in the development of the M. A. N. four-cycle engine. Many people who have seen it state that it is complicated. I feel now, since I am more or less familiar with it, that such statements are made by people who have not given careful thought to what the engine is supposed to do. To bring this point out more clearly, I will take for example, a little device on the forward end of the engine which is used to stop it from the conning tower or the bridge of the vessel. We had a similar device on our gasoline boats in the early days. This consisted of a little switch in the conning tower by which the ignition-system circuit on the gasoline engine could be broken in case of emergency. The same idea was proposed for the Diesel engine, but we had a better interior communication signal on the later boats and we did not see any need for it; submarine officers stated that it simply made the engine more complicated. But if we stop and think for a moment, it becomes very apparent

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that with a larger-sized boat having larger compartments and a big induction valve supplying air to the engine room, when crash diving it is necessary to stop the engines from the bridge to be sure that they are stopped before the main induction valve of the boat is closed. What would happen if the man in the engine room was slow in obeying the signal? Suppose he did not get the signal or was not at his post at the time the signal came through and the induction valve was closed. A vacuum would be produced inside the hull which might kill everybody aboard and cause the loss of the boat. One may not be able to understand at once the reason for everything on a German submarine Diesel engine, but if careful study is made, a very good reason will be found for all of the so-called complications on these engines.

One of the controlling factors in the design of this German engine is the steel castings. I think this is true not only of the German Diesel engine but also of the motorboat engine. The Germans have investigated steel casting to the point where making steel castings is an ordinary, every-day job. I think that has much to do with the success of the German engine, for they have made beautiful steel castings. In this country we have found it difficult to get the steel castings made properly, but after many efforts we are now making a steel casting for the 1200-hp. engine in the League Island Navy Yard with electric furnaces. We employ a 3-ton electric furnace and have done some experimenting which indicates that the trick is in the coring. The steel is poured into the mold and the minute that the metal has set the mold is broken down to get the casting out. The cores are destroyed so that the casting cannot shrink on a stiff hard core. In some of the difficult castings the core is made so that it will crush and, so far, the results have been satisfactory. It is a job that the steel manufacturers of the United States did not want to attempt. But it was felt in the Submarine Service that it was necessary to learn how to make good steel-castings. It must be borne in mind that the German engine is a good type, and the information to the world is three years old. It is not only the United States that has this steel-casting information, all the other nations have it. The Germans pour steel like we pour brass and make no fuss over it. We do not want to be satisfied with copying; we must lead.

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BUFFALO SECTION PAPERS

ALUMINUM PISTONS

By Frank Jardine[1] and Ferdinand Jehle[1]

The paper points out recent developments in aluminum pistons and makes suggestions for their design. The history of the aluminum piston is indicated and a somewhat lengthy resume of the duties of a piston is made, prefacing comments upon the different designs of piston that include formulas.

The operating temperatures of pistons was studied, a series of tests having been made. The results are presented together with lengthy comment thereon and reference to the illustrations. The amount of clearance required for an aluminum piston is treated in some detail, comparative curves between former and present aluminum-piston-clearance practice being shown. It is stated that aluminum pistons have shown certain faults in the past that were defects of design rather than faults due to alloy composition, as is indicated by present practice.

It is not the object of this paper to direct attention to the fact that aluminum pistons, due to their lightness, will reduce the inertia forces, thereby decreasing the engine vibration to a minimum and the bearing pressures to a reasonable amount; nor shall we point out that aluminum has a higher thermal conductivity and therefore reduces carbon deposits both above and below the piston head and permits higher compression pressures. These are advantages of aluminum pistons with which all engineers are familiar. We shall only try to point out the developments of aluminum pistons during the last year or so and to make suggestions for their design. This is, possibly, the age of piston invention and it may not be out of place to quote from Professor Diederich's translation of Güldner's Design and Construction of Internal-Combustion Engines, "Less invention, more rational design." The internal-combustion engine has possibly both benefited and suffered more at the hands of inventors than any other mechanism, and the piston has received a considerable amount of the energy expended in these directions.

Whenever possible it is well to base a design on some-

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thing that is known to have worked well before. It is not our intention to suggest that the engineering fraternity attach the same value to precedent as the legal profession, but it is well to follow closely along the design of something which we know has worked well. The aviation engine owes its success, in a large measure, to the aluminum piston. It would therefore be wise in designing an aluminum piston for automobile engines to follow somewhat along the general lines of aviation-engine practice, taking into consideration the difference in the characteristics of the two engines. It is interesting to follow through the history of aluminum piston design. The first ones were copies of cast-iron pistons which may not have been based on any particular theory. To gain the maximum advantage from lightness, aluminum pistons were at first made very, very thin, and then many ribs were added in the head to make them strong enough. About this time the Liberty-engine piston was designed which eliminated ribs and utilized much heavier sections than had theretofore ever been used in any piston.

The Duties of a Piston

Before discussing the design further let us consider briefly the duties which the piston is called upon to perform. It plays one of the most important parts in transferring a certain percentage of the heat energy in the fuel into mechanical energy and it must also assist to a certain extent in providing a path for some of the waste heat. In the exercise of its first function it is necessary that it reciprocate and to do this with the least amount of disturbance it must be light. Furthermore the gas-engine piston is called upon to do the work which in the steam engine is assigned to three separate parts. It must act as a gas-tight plunger and as the piston-rod, and it must also work as the crosshead.

In performing the function of plunger it must first of all be gas-tight, that is not porous, and must also be of a material which will furnish a good seat for the rings. To perform the duties of a piston-rod and a crosshead satisfactorily, it must fit the cylinder with a minimum amount of clearance so that there is very little play when the engine is cold, but with enough clearance so as not to be tight when the engine is hot. In the performance of its second duty, that of providing a path for heat, it is necessary for the piston to be made of a material which is a good thermal conductor. We know that heat

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enters the piston-head and that a large percentage of this must in time find its way into the water-jacket or cooling fins.

The most important function which the piston performs is that of converting heat into mechanical energy. Providing a path for some of the waste heat is a secondary duty or what we might term "a necessary evil." It is therefore of the utmost importance that the performance of this secondary duty interfere little or none with the performance of the first. Unfortunately up to the present time there has been interference. The heat passing through the piston may cause many undesirable effects such as self-ignition of the charge and excessive expansion of the skirt which necessitates a large clearance when the piston is cold. The first trouble, self-ignition due to a hot piston-head, is eliminated almost entirely by substituting aluminum for cast iron as the piston material. The second, that of clearance, is aggravated by substituting aluminum for cast iron, due to the greater expansion of aluminum.

It has long been recognized that pistons, whether they be made of cast iron or aluminum, must be kept as cool as possible. There has been no agreement among engineers, however, as to how this could best be accomplished. It was thought that if the inside of the piston, particularly the head, were provided with a great number of ribs, much of the heat would be radiated into the inside of the engine and to some degree at least the piston would be cooled by the oil splash. It does not seem reasonable to expect that any great amount of heat can be carried off in this manner. Prof. F. C. Lea, in a paper entitled Aluminum Alloys for Aeroplane Engines which was read before the Royal Aeronautical Society, states

> It is generally claimed that ribs assist in the cooling of the piston by transmitting heat to the air in the crankcase. The heat-balance sheet of an engine, however, shows that the total amount of heat carried away to the crankcase is comparatively small, and therefore, if the ribs are effective from the point of view of conducting heat from the crown to the skirt they are not effective in conveying heat from the crown to the air in the crankcase. Ribs may be required to strengthen the crown of the piston, especially in those of a greater diameter than 4 in., but it is very doubtful whether a large number of ribs such as are used in the Hispano piston, are of any value; one must, however, have an open mind upon this question; ribs certainly add to

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the difficulty of casting. The original sand-cast pistons of the Sunbeam Arab engine had six ribs; by making four ribs instead of six, it was found possible to cast these pistons easily in the die, and running tests showed that the four-rib piston had no disadvantages as compared with the six-rib.

Tests which we have made on ribbed pistons and pistons without ribs on a Hall-Scott engine seem to confirm these results. In these tests a careful record of the temperature of the oil and one of the main bearings were kept. Needless to say the quantity of oil in the crankcase was always kept constant. No difference in the temperature of either the oil or the bearing was detected, which could be attributed to the piston design; although a difference in the temperature of the bearing and the oil could be brought about by a change in the atmospheric temperature.

Designs of Pistons

Col. E. J. Hall made the first piston design which came to our attention that had for its object the direction of the heat flow and provision of a good path from the head of the piston to the water-jacket. Fig. 1 is a diagrammatic sketch showing his general theory. The center of the head *a* must be thick enough to insure against the piston getting too hot at this point. Experiments which Colonel Hall made showed that this thickness should be 7 per cent. of the piston diameter. It is evident that the piston-head thickness must increase from the center to the wall in order to keep the temperature gradient at the minimum. A certain amount of heat enters between *a* and *b*, which amount must be conducted through the area *b-b*. Let us assume for the sake of argument that none of this heat is lost by radiation; then the section *c-c* must conduct all of the heat which the section *b-b* transmitted, plus the heat which entered the piston-head from the area included between *b* and *c*. Each section farther removed from the center of the head of the piston must increase somewhat from the previous section. The scheme then was to provide sufficient metal behind the rings so that the greater portion of the heat would be conducted through this path into the skirt of the piston and thence to the cylinder rather than through the rings to the cylinder wall. His experiments showed that the annular area of the section behind the rings *d-d* should be equal to one-quarter of the total head area. The section *e-e* which is below the rings should have the same

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area. In the skirt we meet the opposite condition from that in the head, for each consecutive section must conduct less heat. Since some heat is transferred into the water-jacket from *e-f* the section *f-f* should have less area than the section *e-e*. By the same reasoning the section *g-g* need not have as great an area as the section *f-f*. When we get to the end of the piston at *h* all of the heat has been lost to the jacket, and therefore *h* need have no area and consequently no thickness. Naturally it cannot be made without thickness for mechanical reasons such as strength in operation and for handling in the shop and foundry. The best thing we can do is to make *h* as thin as practicable. A piston of this general design was used in the Liberty engine and, as is well known, operated in a satisfactory manner. At this point it may be well to quote again from Professor Lea's paper,

> For pistons up to a 4-in. diameter a ribless piston with a domelike crown thickened toward the skirt and with a good fillet where the crown and skirt join is all that is required, and even for larger diameters it seems more than probable that such a construction would prove satisfactory. Experiments at the Royal Aircraft Factory have shown that such a piston runs cooler than one of the same weight with ribs.

Various attempts have been made to apply Colonel Hall's aviation piston to automobile engines with the result that while it worked very well from the thermal standpoint it was too heavy. It must be borne in mind that Colonel Hall's work was all done with pistons of about the same size, 15 in. or over, and with aviation engines. Aviation engines produce much more power per cubic inch of displacement and consequently more per square inch of piston-head area than automobile engines. The amount of heat entering the piston-head of an engine is not a function of its diameter but of the square of its diameter. The latter consideration makes it at once apparent that any formula for the head thickness of pistons varying over a great range of sizes cannot be based upon the diameter but must be based on the diameter squared. The total heat developed in the engine must next be taken into consideration; that is, we must take due account of the fact that the automobile engine produces less power per cubic inch of displacement and square inch of piston-head area than the aviation engine.

We shall now try to write a new formula taking these

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things into consideration. Starting with the Liberty engine operating at 1600 r.p.m. and developing 400 hp. we find that the horsepower per square inch of piston-head area is 400/(19.63 x 12) or 1.7. Letting the head thickness vary with the area of the piston-head and the horsepower developed per square inch of piston-head area, we can write the following formula:

$$T = C_t D^2 H$$

where

C_t = A constant
D = Piston diameter in inches
H = Horsepower per square inch piston-head area
T = Head thickness in inches

In the Liberty piston $T = 0.375$ and $D = 5.0$.
Substituting these values in the formula

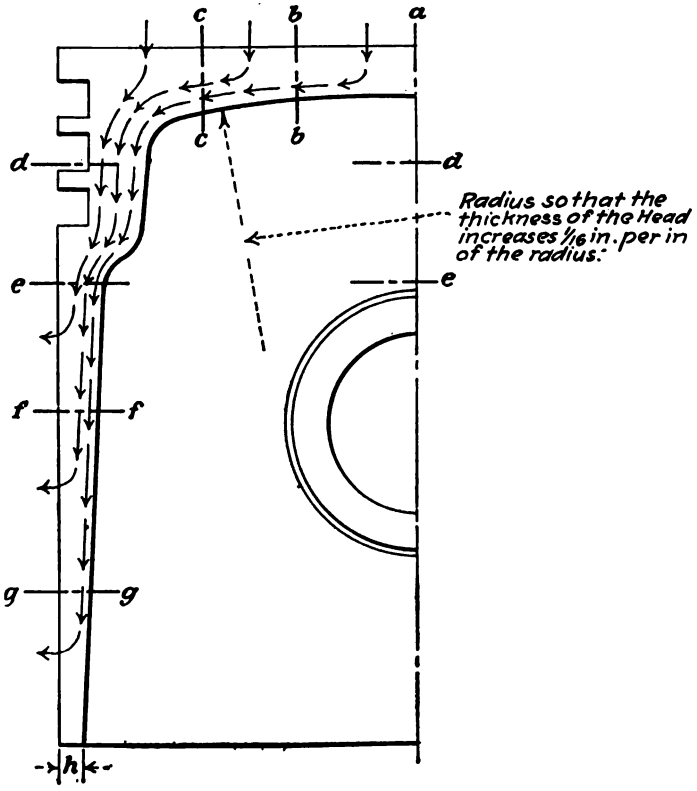

FIG. 1—DIAGRAMMATIC SKETCH OF A PISTON IN WHICH A GOOD PATH IS PROVIDED FOR THE HEAT TO FLOW FROM THE HEAD OF THE PISTON TO THE WATER-JACKET

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$$C_t = T/D^2H$$

we get

$$C_t = 0.0088$$

The wall area will also be a function of the heat entering the piston head. We may express this as follows:

$$A_w = C_wD^2H$$

where

A_w = Wall area in square inches
C_w = A constant
D = Piston diameter in inches
H = Horsepower per square inch of piston-head area

Substituting the values for the Liberty piston of A_w = 4.91, D = 5.00 and H = 1.70 in the formula

$$C_w = A_w/D^2H$$

we get

$$C_w = 0.115$$

In using these formulas the maximum horsepower output of the engine should be used to determine H. It must also be borne in mind that the minimum thickness of the head or the wall depends on foundry practice and will vary for individual cases. It is therefore best to consult with the foundry on this subject.

Operation Temperatures of Pistons

Several years ago we conceived the idea that much could be learned by actually measuring the temperatures of pistons in operation in an engine. For this purpose a single-cylinder Liberty engine was utilized. It was thought best that some means should be provided for conducting the thermocouples out of the engine without subjecting them to any bending whatever. To accomplish this it was necessary to run a straight tube from the piston down through the crankcase. Due to interference between this tube and the standard crankshaft and connecting-rod these parts had to be redesigned. This required much time, and it was not until about a year after the design was made that the first tests were started.

A general layout of the apparatus in its early stages is shown at the left of Fig. 2. The couples terminated at the cold junction-point shown in the diagram and the leads from there to the potentiometer were made of piano wire. This arrangement looked very promising for a while, but it was too heavy and the fastening connecting the piston to the tube was broken. It was then de-

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cided to eliminate the pantagraph arrangement and let the piano wire form the connection between the cold junction and the potentiometer unsupported. To eliminate vibration of the wires as much as possible they were placed in narrow channels which permitted motion in only the vertical plane. The upper right portion shows this set-up, while a more detailed arrangement of the channels is given underneath.

Fig. 3 is a diagram of the pistons showing how the couples were attached and their location. Couple No. 1 is in the center of the head, No. 2 is on the intake side at right angles to the plane of the wrist-pin, 1⅝ in. from

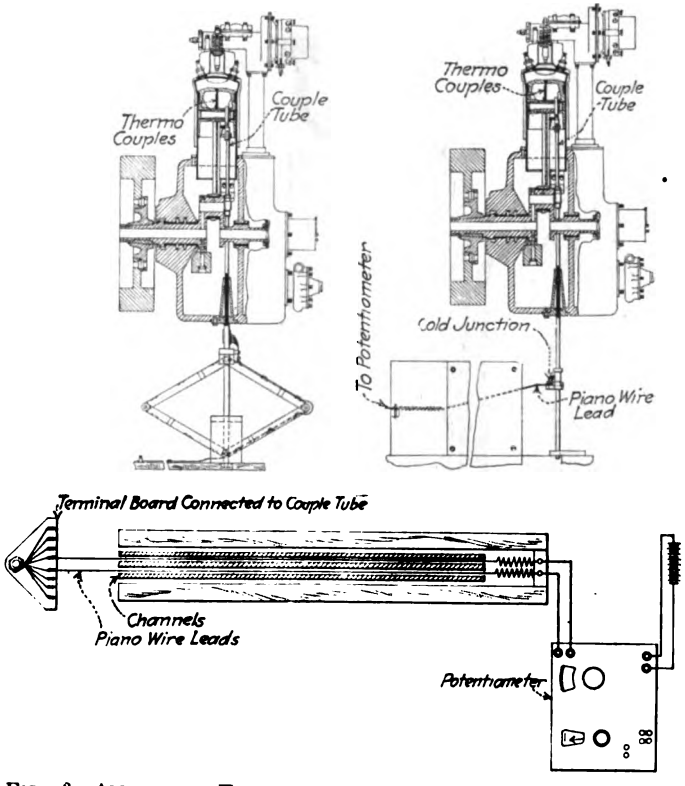

FIG. 2—APPARATUS EMPLOYED IN DETERMINING THE OPERATION OF ALUMINUM PISTONS

The General Arrangement of the Apparatus First Used Is Shown at the Left and at the Right Is Illustrated the Set-Up That Was Finally Employed with a Detail of the Channels for the Piano-Wire Leads Underneath

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the center of the head, No. 3 is on the intake side below the rings, 2 in. from the top of the head, and No. 4 is located ¼ in. from the bottom of the skirt, also on the intake side. Several methods were used at different times for fastening the couple to the piston and two are shown in Fig. 3. The first one was to drill a comparatively large hole about ¼ to ⅜ in. in diameter partially through the piston and a small hole the rest of the way. The couple was inserted through the small hole and bent over as shown, and a plug screwed tightly against it. This gave very satisfactory results. The point was

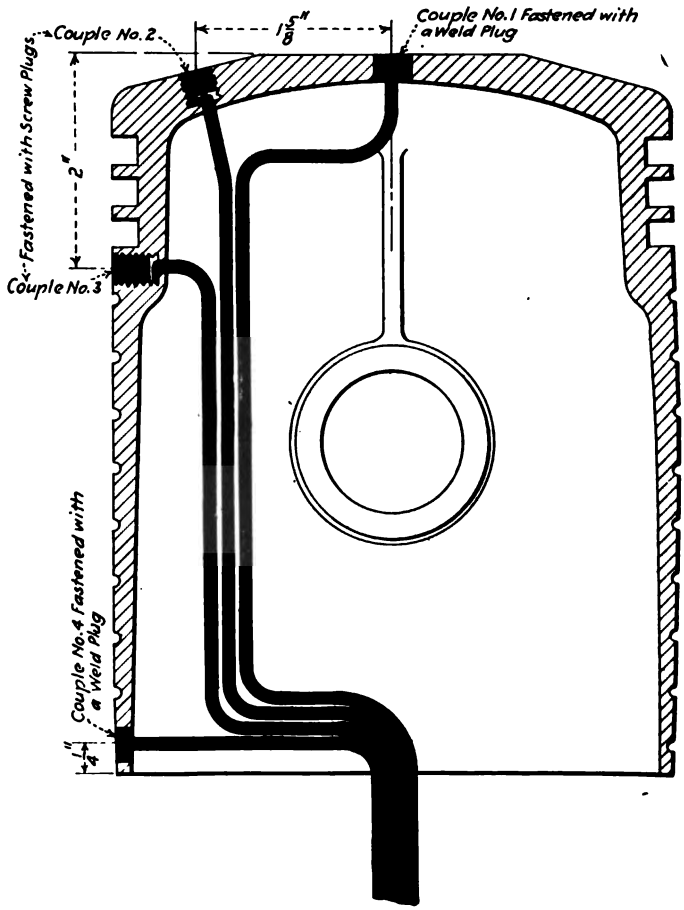

FIG. 3—ARRANGEMENT OF THERMOCOUPLES IN THE PISTONS

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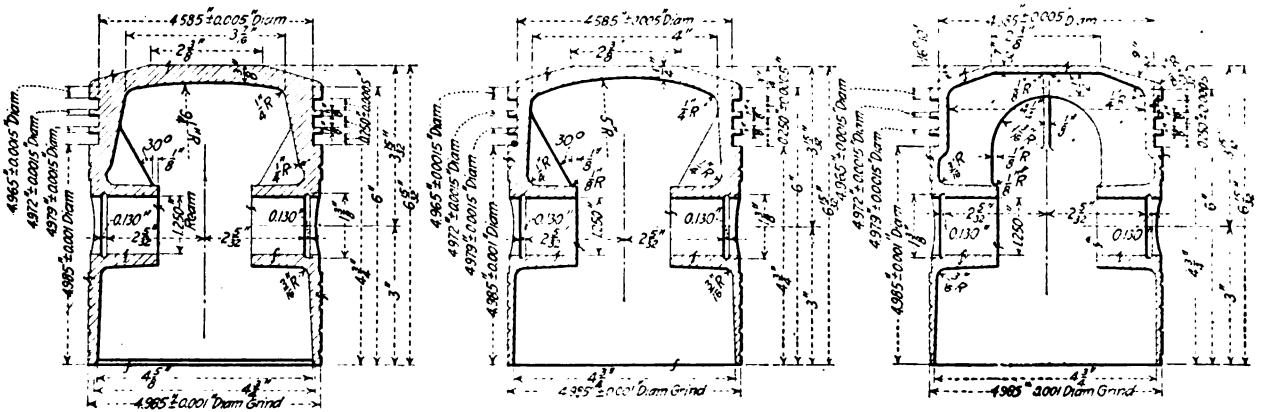

FIG. 4—SECTIONS OF THE THREE PISTONS USED IN MAKING THE TESTS

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raised, however, as to whether or not the plug had a sufficiently good contact with the rest of the piston to insure that it was not hotter than the piston itself. To investigate this point some of the couples were inserted in a similar way to the one outlined except that instead of inserting the screw plug the large hole was closed by welding. This was a rather difficult weld to make but those pistons in which the weld stood up showed no difference in temperatures over those using the screw plug. In all cases the head couples were inserted 1/16 in. from the inside of the piston.

The results of the piston-temperature tests given below are not considered as final but are sufficiently conclusive to indicate the temperature distribution in pistons. The first tests were made with a piston designed according to the Hall formula mentioned above. Even the preliminary tests made with these first pistons showed that the heat did not follow the outlined path to the water-jacket. The greatest temperature-drop was noted between couples Nos. 2 and 3, that is through the rings, while the drop through the skirt was not as large as that through the ring section. At this point we would like to bring out the similarity between the results obtained by Arthur A. Bull, of the Northway Motor & Mfg. Co. and ourselves, although Mr. Bull's work was done on a stationary piston in a water-jacketed cylinder.

It was then decided to make up several pistons of different thicknesses and constructions and note the difference in temperature distribution. Fig. 4 is a set of detail drawings of the pistons that were used. The amount of metal in each one is best expressed by the weights, which are, from left to right, 3.9 lb., 3 lb. and 2.5 lb. Since it was not certain that the apparatus would work at high speeds it was thought best to make all of these tests at 800 r.p.m. or as nearly that speed as possible. Fig. 5 shows the results obtained from these tests on the different pistons, the figures around the outline indicating the temperature at the various points and the drop between them. The average speed of all the tests was 800 r.p.m., the average brake-horsepower 13, and the average cooling-water temperature, inlet, 126 deg. fahr. and outlet, 147 deg. fahr. In the piston at the left which was the heaviest, the drop across the rings was 280 deg. fahr. and the drop across the skirt only 105 deg. fahr. In the next lighter piston which is shown in the center the drop across the rings was 349 deg. fahr. and the drop

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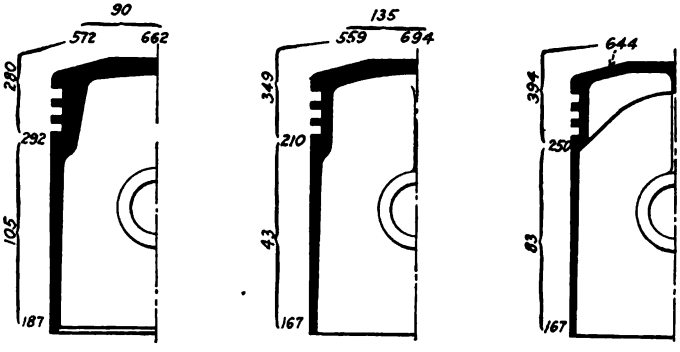
across the skirt 43 deg. fahr. In the lightest piston tested, that at the right, and which incidentally had two cross ribs, the drop across the rings was 394 deg. fahr. and the drop across the skirt was 83 deg. fahr. It is interesting to compare these results and at once it becomes apparent that in spite of any section we can put behind the rings and on the skirt the greatest temperature-drop is across the rings. It is therefore very obvious that the original



	Speed, r.p.m.	
800	800	800
	Brake horsepower	
12.9	13.1	13.2
	Inlet Water Temperature, deg. fahr.	
128	126	126
	Outlet Water Temperature, deg. fahr.	
148	145	147

FIG. 5—RESULTS OBTAINED FROM TESTS OF DIFFERENT PISTONS SHOWING HOW VARIATION IN THE DESIGN AFFECTS THE TEMPERATURE IN OPERATION

Hall idea of by-passing the rings is not absolutely correct. It is just as apparent, however, that the amount of metal behind the ring grooves does affect the temperature drop. Comparing the three pistons we find that the drop across the rings is less when more metal is used behind them.

Calculating a wall area based on the power developed by the engine at this speed we would get an area slightly less than the one shown at the right of Fig. 5. It would therefore seem that the formula developed for wall area does not call for too much metal; in fact slightly more would do no harm. The piston mentioned is a trifle on the thin side for mechanical reasons and more metal should be added on that account. The formula for wall area behind the rings should, therefore, for the present at least, be adhered to. The results would seem to indicate, however, that it is not necessary to have as much

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metal immediately below the rings or in the section *e-e* in Fig. 1. The skirt thickness should therefore be determined largely by casting, machining, and other mechanical requirements.

The next interesting point to be considered is the temperature of the head. Unfortunately more trouble was encountered with the couple in the center of the head than with the other couples used and in the one case, that of the piston at the right of Fig. 5, no successful reading was obtained. By comparing the other pistons, however, we can see that some difference can be laid to the thickness of the head. A difference of 32 deg. fahr. was recorded between the center head-temperature of the pistons at the left and center. The temperature toward the side of the head as measured by Couple No. 2 was actually a few degrees higher in the thicker piston. This can be explained in three ways, (*a*) the difference of 12 deg. fahr. is possibly as close as any two pistons of the same design would operate, (*b*) it may show that for the amount of horsepower developed the central piston had a head of sufficient thickness, and that a greater thickness would not be of any benefit, and (*c*) the temperature difference across the thinner head would naturally be greater than that across the thicker head. Couple No. 2, in the lightest piston shown at the right of Fig. 5, however, was 72 deg. fahr. hotter than the similar temperature for the piston at the left. That, without a doubt, is due to the head thickness. According to the formula the first of these two pistons had a head thicker than necessary, but the temperatures obtained would seem to indicate that it was not too thick. If more taper had been used, that is, if the head had been made thicker where it joins the skirt the temperature of 644 deg. fahr. would have been reduced somewhat. Until such time as further work can be done it is wise to adhere to formulas outlined above because passenger-car pistons designed in that way have given good results.

Comments on the Tests

In making these temperature tests other troubles were encountered besides the mechanical workings of the parts. It was discovered that piston temperatures, especially that of the head, were very susceptible to changes in fuel-consumption. A sufficient amount of data has not been collected on this subject for presentation in this paper but we can state that it warrants further investi-

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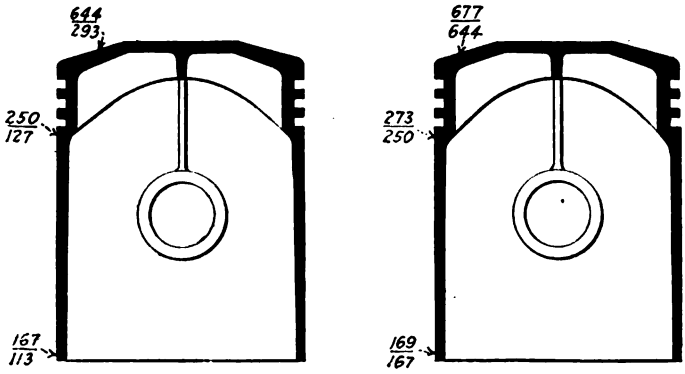
gation. All the tests reported herein were made with the same fuel-consumption.

It was also discovered that changes in cooling-water temperatures brought about a marked difference in the piston temperatures. The temperature at the lower end of the skirt is dependent, largely, upon the temperature of the cooling water. Sufficient time was not available to go into this problem as thoroughly as would have been desirable but enough data were collected to show the effect of an extreme change in water temperatures as



The Upper Temperature Readings Were Obtained at a Speed of 800 R.P.M. and Brake Horsepower of 13.2 and Inlet Water Temperature of 126 Deg. Fahr. and an Outlet Temperature of 147 Deg. Fahr. The Corresponding Values for the Lower Readings Were 800 R.P.M., 14.0 B. Hp. and 48 and 58 Deg. Fahr.

The Upper Temperature Readings Were Obtained with a Speed of 1000 R.P.M. and 16.2 B. Hp. and the Lower with a Speed of 800 R.P.M. and 13.2 B. Hp. The Inlet Water Temperature Was 126 Deg. Fahr. and the Outlet 147 Deg. Fahr. Throughout

FIG. 6—TEMPERATURE DIFFENERCES DUE, AT THE LEFT, TO A VARIATION IN COOLING-WATER TEMPERATURES AND AT THE RIGHT TO A CHANGE IN SPEED

shown at the left of Fig. 6. Unfortunately these tests were made on the piston in which the center head-couple was inoperative. Couple No. 2 on the head, while the inlet cooling-water temperature was 126 deg. fahr. and the outlet 147 deg. fahr., indicated a temperature of 644 deg. fahr. When the water temperature was reduced to 48 deg. fahr. for the inlet, and 58 deg. fahr. for the outlet, this temperature dropped to 293 deg. fahr., that is, it dropped 251 deg. Couple No. 3, below the rings, showed a drop of from 250 to 127 deg. fahr., or 123 deg., for the same change in cooling-water temperature. Couple No.

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4 at the bottom of the skirt fell from 167 to 113 deg. fahr. It is also interesting to note that the drop across the rings decreased from 394 to 166 deg. fahr. and that across the skirt from 83 to only 14 deg. fahr.

Due to a lack of time it was not possible to study thoroughly the effect of engine speed on the temperature. The right half of Fig. 6 gives the result of one set of tests made at 800 and 1000 r.p.m. The water temperature of both tests was held at 126 deg. fahr. for the inlet, and 147 deg. fahr. for the outlet. The horsepower at 800 r.p.m. was 13.2 and at 1000 r.p.m. it was 16.2 hp. The head temperature was increased from 644 deg. fahr. at 800 r.p.m. to 677 deg. at 1000 r.p.m., an increase of 33 deg. The temperature below the rings was increased from 250 deg. fahr. at 800 r.p.m. to 273 deg. at 1000 r.p.m., an increase of 23 deg. The temperature of the lower end of the skirt remained the same; the increase of 2 deg. from 167 to 169 deg. is not outside the limits of error. Judging from the results so far obtained the speed has little effect on the skirt temperature. Before stating this definitely more tests should be run and such tests are contemplated.

Clearance Required

As shown by the tests much of the heat leaves through the rings. The temperature immediately below the rings is at times several hundred degrees lower than the head temperature. Since thermal expansion is a function of the temperature it would seem, offhand, that this state of affairs would be ideal. We know, however, that the clearance required for aluminum pistons is much in excess of that necessitated by skirt temperatures. There can be only one explanation of this and that is, that the hotter piston head will cause a mechanical expansion of the skirt in addition to the thermal expansion due to its temperature. The force set up in a structure due to its temperature is really enormous, as a simple calculation will show.

$$\text{Modulus} = \text{Unit force} \div \text{Unit deformation}$$

then

$$\text{Unit force} = \text{Modulus} \times \text{Unit deformation}$$
$$\text{Modulus for aluminum} = 10{,}000{,}000$$
$$\text{Unit deformation for 1 deg. fahr. rise} = 0.000012 \text{ in.}$$

Substituting

$$\text{Unit force} = 10{,}000{,}000 \times 0.000012$$
$$= 120 \text{ lb. per sq. in. per deg. fahr.}$$

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Bearing in mind that the difference between the skirt and head temperatures is at times several hundred degrees we can get some idea of the magnitude of this force. There can, therefore, be no question that the expansion of the head is accountable for much of the clearance which must be given to the skirt of a piston.

If the skirt could be entirely separated from the head the clearance could be greatly reduced. It is not practicable, however, to separate the head entirely, but it can be separated from certain portions of the skirt so as to relieve the skirt of mechanical expansion in certain directions. The most reasonable place to reduce the expansion in this manner is across the thrust faces. A saw slot immediately below the lower ring on both the thrust faces will bring about this condition. The mechanical expansion of the skirt in the direction of the axis of the wrist-pin will remain unaltered and some means must be provided for making this expansion harmless. This can be done by relieving these faces for their entire length or providing some flexibility by a slot. Both methods have been used and have given satisfaction. By separating the skirt from the head we eliminate mechanical expansion in one plane, that is, across the thrust faces. Supposing we consider a piston with its head and skirt separated as just mentioned, running under conditions such as were shown in some of the temperature charts, with an average head-temperature of 600 deg. fahr., a rise of 530 deg. above room temperature, the expansion of the head would be 0.032. The skirt temperature in this same test was 210 deg. fahr., a rise of 140 deg. above room temperature. This on a 5-in. piston gives an expansion of 0.0085 in. The mean cylinder-wall temperature is the average between the piston-skirt temperature and the cooling water, that is 178 deg. fahr., 108-deg. rise over the room temperature. This would give a cylinder-wall expansion of 0.003 in. The clearance necessary should then be the difference between the piston expansion and the cylinder expansion, which in this case is 0.005 in. This would give us no clearance for an oil film and the piston would seize. Tests which we have made prove that 0.005 in. is enough for a piston of this description running up to 1600 r.p.m. at which the skirt temperature is undoubtedly somewhat higher than at 800 r.p.m. The clearance which we know is necessary for the piston is less than the temperature would seem to indicate. This can be explained in the

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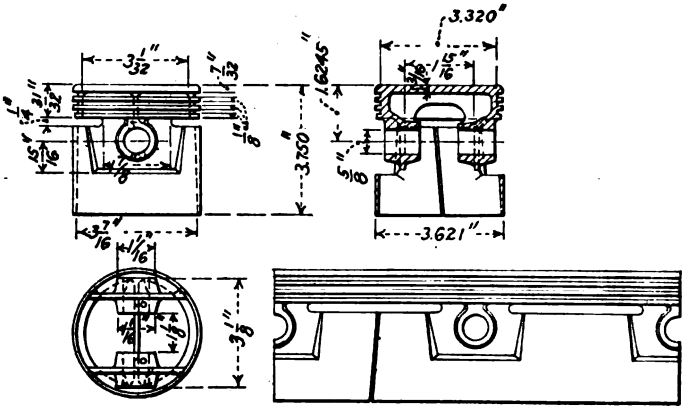

FIG. 7—A PISTON USING A SLOT TO COMPENSATE FOR THE EXPANSION OF THE HEAD

following way: The expansion of the head is acting on that portion of the piston skirt which is not separated from the head by slots and is imparting to it a mechanical expansion in addition to the thermal expansion.

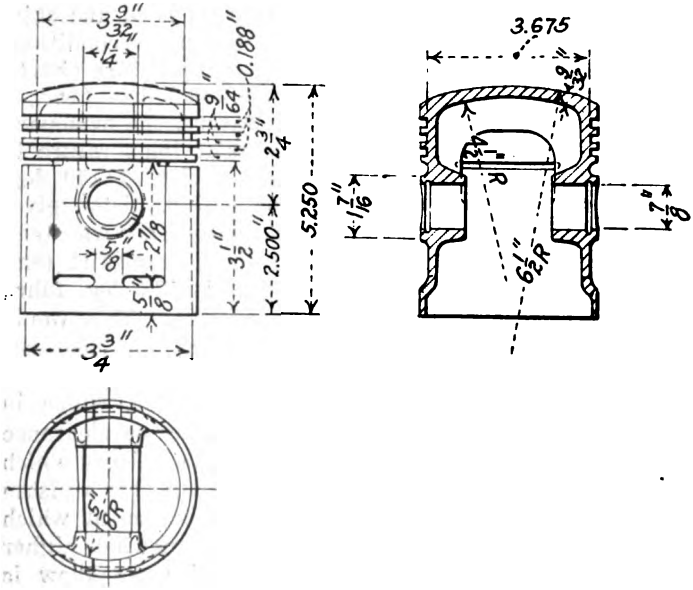

FIG. 8—IN THIS PISTON THE MECHANICAL EXPANSION DUE TO THE HEAD IS TAKEN CARE OF BY RELIEVING THE SIDES

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If a circle is expanded only along one diameter it will have to contract along the diameter at right angles to it, that is the circle will be changed into an ellipse by shortening one of its axes and lengthening the other. The mechanical expansion along the axis of the wrist-pin has been made harmless by either relieving the piston at the ends of the wrist-pin or by giving it flexibility by a vertical slot.

Fig. 7 shows a piston which makes use of the flexibility by means of a slot to correct for head expansion. This type is in use in the Maxwell car. Fig. 8 shows a

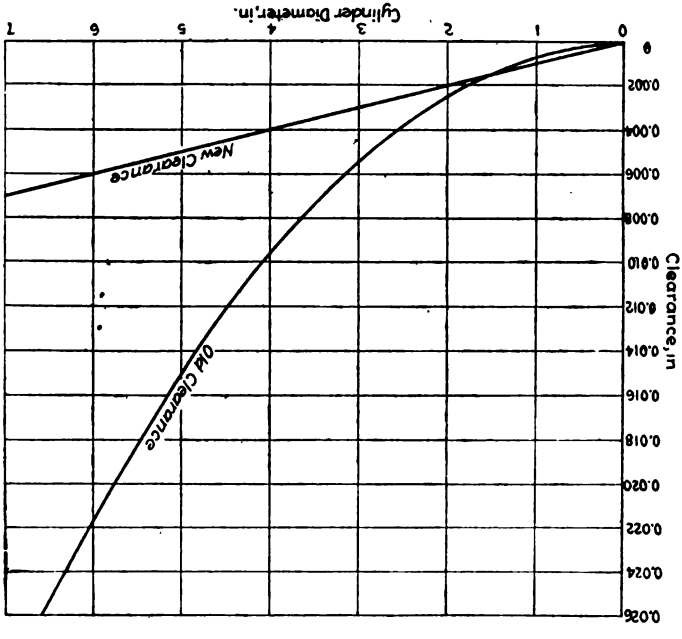

FIG. 9—COMPARISON OF THE CLEARANCE FORMERLY USED ON ALUMINUM PISTONS AND THAT NOW PREVAILING

piston in which the head is separated from the skirt on the thrust faces and the mechanical expansion due to the head is taken care of by relieving the sides as shown. This type is in successful operation in Northway engines. In making slots it should not be overlooked that these should be made as wide as possible so as to allow a free passage of the oil back into the crankcase. In providing a relief on the sides this should be of ample depth. Holes of a large size or preferably a short slot at the bottom

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of the relief should be provided so that oil accumulated in the relief can pass away easily and quickly.

The successful operation of pistons is measured by the minimum clearance necessary for satisfactory performance. The progress of aluminum pistons within the last few months can be shown best by comparing the clearance curves in use now with those in use several months ago. Fig. 9 shows these two curves, both of which are based on experiments. The top curve shows the clearance necessary for pistons of the old conventional type and the lower the clearance necessary for the types just mentioned.

It is, of course, impossible to lay down this curve as a definite law. Engine temperatures undoubtedly depend on engine design and piston temperatures depend upon piston clearance. While these curves were determined from actual practice the characteristics of all engines may not be the same and some variation might be found necessary. The actual clearance required can be determined only by tests in each case but the clearance on the curve represents a safe starting-point for these tests. In the past aluminum pistons have shown certain faults but present practice indicates that these faults were faults of design and not faults of alloys.

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THE CONSEQUENTIAL ADVANTAGES OF WEIGHT REDUCTION

By L H Pomeroy[1]

Stating that it is conceded by engineers that weight reduction is desirable economically but that it is not unusual to find that weight reduction is looked upon as incompatible with reliability and road-holding properties, the author outlines briefly the normal weight-distribution in an automotive vehicle and gives a short analysis of the power required to drive it, having in mind the necessity of reducing the absolute friction-loss.

The use of aluminum for various parts is debated, especially those in which reliability is distinctly a function of lightness and not of weight, such as engine pistons, and the application is made general to cover all parts of an automobile in which the stresses are determined by road shocks and speed. The trend of design in general and recent research in particular are stated to be along the lines of weight reduction without any sacrifice of essentials.

It is generally admitted by engineers that any steps toward the reduction of chassis and body weights are desirable in the interests of economy but it is not unusual to find that weight reduction is looked upon as incompatible with reliability and road-holding properties. The weight of an automobile chassis is determined on the one hand by the engine power and the required strength of the transmission to transmit the torque developed and on the other by the strength of the axles, springs and frame in their relation to the shocks imposed by road inequalities and driving strains. In brief, if automobiles had to be designed to run on railroad tracks up mountains the engine and transmission would be the chief determinant of the total weight as the shocks imposed on the axles and the frame would be very small. Conversely if automobiles had to be designed to run from the top of a mountain to the bottom over very rough roads the weight would be principally determined by the requirements of the frame, springs and axles.

Apropos of this the rear-axle is a member which supports the weight of the car and also transmits the engine torque to the wheels, while the front axle is vir-

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tually a load-carrying member solely, its stresses being independent of the engine torque for any given speed and car weight. It is a matter of simple calculation to determine the remarkably small average horsepower developed in the propulsion of a full-sized passenger car. At 30 m.p.h. this amounts to about 8 hp. and in the majority of cases is not more than 25 per cent of the horsepower available. Taking a typical case of an engine say of 240-cu. in. cylinder capacity, a gear-ratio of 4.5 to 1 and 32-in. wheels, the engine speed corresponding to 30 m.p.h. is approximately 1350 r.p.m. while about 36 b.hp. is available at that speed. Approximately 4 hp. is absorbed in internal friction so that the 8 hp. required to propel the car is attended with a loss of 4 hp. and the mechanical efficiency of the engine under these conditions is only about 66 per cent. This simple calculation indicates the necessity not only of obtaining high mechanical efficiency in automobile engines, but of reducing the absolute friction loss as it is such a large proportion of the average power exerted. It is obvious that the larger the engine the greater the absolute loss and one of the consequential advantages of reducing the size of the engine, in addition to the reduction in weight, is that its absolute friction loss is proportionally reduced, apart altogether from mechanical efficiency as such.

Aluminum for Various Parts

The use of aluminum for pistons is a well-known method of reducing inertia stresses and bearing pressures and in conjunction with the use of forged aluminum connecting-rods reveals the possibilities of wholesale weight reduction. The factor which probably determines the maximum horsepower that can be continuously developed is the loading on the big end of the connecting-rod. This is very largely a function of the mass of the piston and connecting-rod at high speeds so that if this total mass can be halved as is easily possible by the use of aluminum, the safe engine speed can be increased over 40 per cent, or alternatively the same engine speed can be maintained with a 40-per cent reduction in the amount of bearing surface. I am fully aware of the difficulties in utilizing this idea to its fullest extent, but it is seriously suggested that the possibilities of weight saving by shortening bearing lengths is full of the greatest potentialities.

The example of the piston and connecting-rod, in

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which reliability is distinctly a function of their lightness and not of their weight, applies in general to all parts of an automobile in which the stresses are determined by road shocks and speed. It is of the utmost importance, therefore, in the interest of reliability to reduce the weight of all parts which are so stressed. This is particularly emphasized in axle design where the effect of road shocks is strictly proportional to the axle weight. In addition axle weight reduction brings with it enhanced road-holding properties as the relation of sprung to unsprung weight is reduced. The argument in support of this is precisely analogous to that demonstrating the necessity of light valve-gear on a high-speed engine. The extended use of aluminum makes axle weight reduction possible and I would call attention to an axle I have recently designed in which the complete weight of the axle together with brake drums, aluminum disc wheels and tires is about 290 lb. This axle has been driven some 11,000 miles as fast as possible over very bad roads and has demonstrated conclusively its reliability and furthermore the fact that good road-holding is just as practicable in a light car as in a heavy one.

Engine size and chassis weight pursue each other in a vicious circle. Because the engine is large it is necessary that the running-gear and transmission shall be heavy, and because the latter is heavy it follows that the engine size must be increased to get any desired performance. By tackling the problem of reduction literally from the engine to the wheels, the amount of weight which can be saved without sacrificing reliability is surprising. The result is that with a car of the same general type a very much better performance is obtained. If improved performance is not required it is then possible to redesign and maintain the previous performance with a still greater reduction in the weight. One needs experience with the full-size light car to appreciate its economy, reliability, power of acceleration, speed and handiness. The trend of design in general and recent research in particular are along the lines of weight reduction without any sacrifice of essentials.

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CLEVELAND SECTION PAPER

THE PACKARD FUELIZER

By L M Woolson[1]

The general requirements for ideal carburetion are considered first, as an introduction to what the Packard fuelizer is and how it functions. Since it is difficult to secure uniform distribution with what is termed a wet mixture, this problem is discussed in general terms and it is stated that the fuelizer was evolved only after several different types of exhaust-heated manifold had been tested and found wanting.

Detonation is treated at some length, four specific rules being stated that apply to the most desirable mixture temperatures to be maintained, and the source of the ignition spark for the fuelizer is discussed as an important element in the device. Further consideration includes comments upon the comparative merits of the hot-spot and the fuelizer, "hot-spot" being intended to mean any of the exhaust-heated manifold-designs in which the heat is more or less localized.

To present in the proper light what the Packard fuelizer is and how it performs its functions, it is advisable to consider briefly what the general requirements are for ideal carburetion under varying conditions. Let us consider first the basic engine such as is shown in Fig. 1. There are three main elements of the design with which we are concerned; the carbureter or fuel-metering device, the manifold, and the combustion-chamber. Each of these elements has its particular functions to perform. The carbureter must furnish a suitable mixture over a wide range of speeds and loads; the manifold must distribute this mixture in a suitable condition and in a uniform manner to the various cylinders, and the combustion-chamber must permit complete combustion of the fuel. None of these elements can perform the functions of another; if the carbureter does not produce the desired mixture the manifold cannot deliver it to the cylinders, and if the manifold does not deliver a uniform mixture to the different cylinders, conditions in the combustion-chambers naturally will vary.

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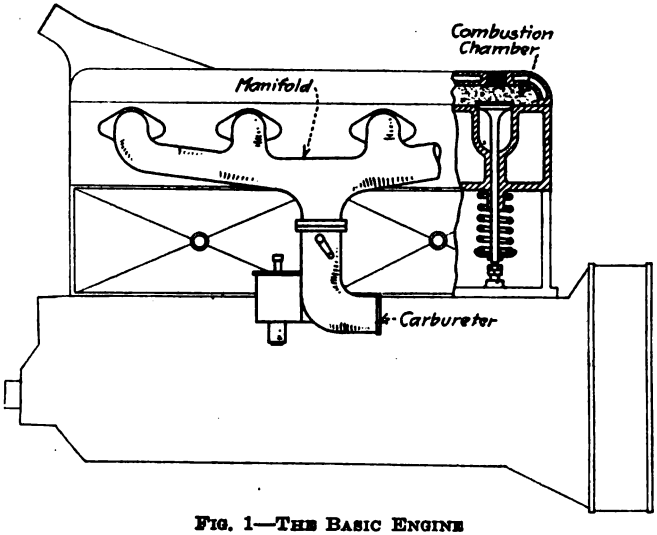

FIG. 1—THE BASIC ENGINE

Considering the carbureter first, this has been developed gradually to a point where reasonably good operation is assured, and the metering characteristics are sufficiently accurate for practical purposes over a wide range of conditions. The average carbureter, if properly adjusted, will deliver a 15 to 1 substantially constant mixture, or whatever may be desired, under all ordinary running conditions. There is much work to be done in making the carbureter produce the varying mixtures actually required for the most efficient operation of the engine under varying conditions. However, at present we are concerned with the supply of a mixture of air and gasoline maintained at practically a constant ratio under varying load and speed, and in this respect the modern carbureter can be considered satisfactory.

It must be admitted that manifold design has been largely a matter of trial and error. There are a few well established rules to follow but, in general, we build the manifold first and fit a theory to it afterward. Almost any design of manifold will deliver a mixture of gases in a very uniform manner to the several cylinders, but when we attempt to distribute a mixture of air and liquid gasoline particles we find it extremely difficult to obtain uniform distribution. The gasoline particles can be considered as occupying the relative space shown in Fig. 2. Their volume is only 0.01 per cent of the volume

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of the air in the manifold. Furthermore, their weight for a given volume is about 560 times the weight of the same volume of air, with a correspondingly greater inertia. Therefore, it is not surprising to find that, if the gasoline is in the manifold in a liquid state, uniform distribution is practically impossible. Gasoline is not an homogeneous substance with a fixed boiling-point, but is of a very complex nature and various fractions of it boil at various temperatures. Furthermore, the fuel will be broken up mechanically to a greater or less extent, dependent upon the jet construction and the atomizing means, if any, which may be employed; so, the manifold is called upon to distribute a mixture of gasoline and air which has practically the same chemical composition for all carbureters. The physical structure of this mixture depends, however, upon several variables; but, in general, the mixture, as delivered by the carbureter to the manifold, is at best merely a spray of liquid gasoline mingling with the air current.

We find a great variety of designs of combustion-chamber, dependent largely upon the valve arrangement; the L-head, T-head, overhead and F-head arrangements, each of which produces a combustion-chamber with a certain characteristic shape. The behavior of the mixture of gasoline and air after entering the cylinder is determined to a certain extent by the shape and design of the combustion-chamber. Generally speaking, however, the troubles which the fuelizer was designed to overcome are common to all forms of combustion-chamber. There is, however, much to be done in combustion-chamber design to eliminate or diminish detonation, which in itself represents a large field for study. This point serves to bring out again that each of the three elements of the engine which we are considering has its own problems. Detonation is largely a matter of combustion-chamber conditions and is related only indirectly to manifold conditions.

Uniform Distribution

It is difficult to secure uniform distribution with what we term a wet mixture. There are two other main reasons why wet mixtures are undesirable, especially when the engine is working on part throttle under reduced load, as is the case in automobile practice fully 90 per cent of the time. First, spark-plug fouling has been found to be brought about almost exclusively by wet-mixture conditions. It has been shown that an excess of

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lubricating oil in the combustion-chamber is not responsible for fouled spark-plugs, as was commonly thought. In fact, if an engine is supplied with a dry mixture, the spark-plugs will continue to function in spite of an excess of clean oil that may be present. We hear often that some engines pump oil in certain cylinders and foul spark-plugs by so doing but, as a matter of fact, experiments

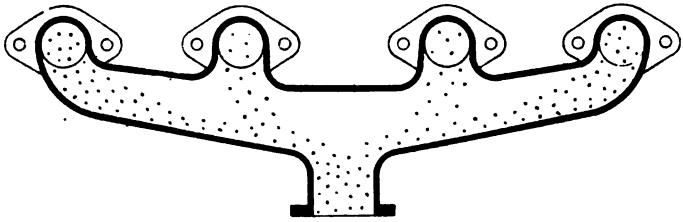

FIG. 2—DIAGRAM SHOWING MIXTURE CONDITIONS IN THE MANIFOLD

have shown that this is merely a mixture condition associated with poor distribution. It is the end cylinders of an engine that will be said to pump oil and foul spark-plugs as a general rule. The reason is that, in nearly all manifold designs, there is a tendency for the heavy gasoline particles to continue in a straight line to the end of the manifold. There they turn in and thus bring about these spark-plug fouling conditions. There is also the problem of the dilution of the lubricating oil by so-called kerosene, which is a familiar condition. This has been considered formerly as a cold-weather condition only, but many cars are bad offenders in this respect in even moderately warm weather. I believe that these facts are recognized universally at present and that the desirability of a dry mixture, at least for part-throttle work, is self-evident.

Many methods of supplying the requisite amount of heat to the intake-manifold have been tried. The use of heat from the exhaust gases has been favored recently, and many schemes have been evolved with the idea of concentrating the heat where it will do the most good. I will not attempt to discuss these various devices in detail but will state that the fuelizer was evolved only after several different types of exhaust-heated manifold had been tested and found wanting in some particular or other. The trouble was not that there was insufficient heat available in the exhaust, since the exhaust may contain from 25 to 50 per cent of the heat units obtainable from the

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original fuel. As a matter of fact, considerably less than 5 per cent of the heat contained in the fuel which the engine is using is required for vaporizing purposes. The main point has been that the exhaust heat is represented by a comparatively large volume of gas at a comparatively low temperature, and what is required for the efficient application of heat to an intake-manifold is rather a limited amount of gases at very high temperatures.

Another reason for this latter requirement is that it involves a very simple means of regulating the heat in accordance with the work the engine is performing. As is well known, the volumetric efficiency of an engine is dependent upon the weight of the charge drawn in, and it is obvious that if we heat the charge it will expand. A given volume of the heated charge will weigh less than the same volume of cool charge; consequently the output of the engine will be decreased in proportion to the temperature rise of the mixture. The extent of this loss in volumetric efficiency can be judged when we consider that for each fahrenheit degree rise in temperature there is a loss in weight for a given volume of about 0.2 per cent, so an increase of say 100 deg. fahr. would mean a loss in output of something like 20 per cent.

Detonation

There is another serious disadvantage in maintaining the mixture at too high a temperature under wide-open-throttle work. This is in connection with the phenomenon of detonation, which has been recognized only lately to be the cause of what is familiarly termed "spark knocking" or "spark hammering." When a charge is ignited in the combustion-chamber, the flame propagates in all directions from the point of ignition and, if the engine is working on full throttle, it may happen that some of the charge will be so highly compressed by the advancing wave of flame that it will detonate. The momentary pressure due to detonation may be three or four times as great as the pressures brought about by more gradual combustion. There are many factors influencing detonation; the general shape of the combustion-chamber, the location of the spark-plug, the compression-ratio, the extent and thickness of the carbon deposit upon the combustion-chamber walls and piston-head, the temperature of the jacket water and temperature of the incoming charge. It will be seen readily that if the temperature of the incoming charge is greater, a proportionately

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larger amount of highly-compressed unburnt-mixture will detonate.

The theory has been advanced that, within reason, the higher the temperature of the incoming mixture is, the better the fuel efficiency under wide-open-throttle conditions will be. However, this has not been borne out in practice. The Bureau of Standards has confirmed this by recent tests which show that, when running wide-open, there is very little if any connection between fuel economy and mixture temperature. In the matter of acceleration, however, a paradoxical condition prevails. Although we have seen that volumetric efficiency falls off with increase of mixture temperature, it is true that the accelerating quality of an engine is very much improved by an increase in mixture temperature. This also has been confirmed by some recent Bureau of Standards' tests. I have driven cars with mixture temperatures exceeding 400 deg. fahr. which had extremely good acceleration. However, when a hard steady pull up a steep grade or through heavy going is required, a cool mixture gives by far the best results, owing to the improved volumetric efficiency. Incidentally, there seems to be no disadvantage in using relatively cool mixtures under wide-open-throttle conditions. This is no doubt due partly to the high temperatures prevailing in the combustion-chamber and on the piston-head and, as is well known, spark-plug fouling and crankcase dilution are not ordinarily associated with wide-open-throttle work. Accordingly, we find that the following rules apply as to the most desirable mixture temperatures to be maintained:

(1) For idling, fairly high temperatures are to be attained as quickly as possible after starting, to avoid loading, spark-plug fouling and crankcase dilution

(2) For slow running on part throttle, an equally high temperature is desired. Very good results for this work are given by a temperature of 180 deg. fahr.

(3) For accelerating, a similarly high temperature is desirable

(4) For continuous wide-open-throttle work, the lower the temperature is, the greater the power will be; although a mixture temperature below 100 deg. fahr. with present-day gasoline is not advocated. This is merely a concession to good distribution

As to why distribution under wide-open-throttle conditions does not demand an equally dry mixture, as has been

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stated was desirable for low-throttle work, practical experience with many types of engine has shown that in every case good distribution can be obtained with proper manifold design and without supplying more heat to the mixture than can be supplied through the water-jacketed passages which are commonly integral with the cylinder. This is substantiated by fuel-consumption tests such as were conducted by the Bureau of Standards, with the mixture at various temperatures. This condition does not necessarily apply to lower-grade fuels such as kerosene. I believe we have an insufficiently thorough theoretical knowledge of distribution to prove this point, although we know that with the increased mixture velocities met with in wide-open running there is less tendency for the liquid particles to separate from the air-stream and condense on the manifold walls. It is this condensation or deposition that is responsible for poor distribution of wet mixtures with low mixture-velocities. Then again, under a wide-open-throttle condition, the increased compression pressures, the higher temperatures of the combustion-chamber walls and the increased turbulence all assist in carrying out the combustion of a wider range of mixtures than would ignite under less favorable conditions.

IGNITION

The source of the ignition spark for the fuelizer is an important element in the device. There are several different ways of securing the necessary current but, as a result of experience, certain methods have proved the most desirable. With battery-ignition systems, a separate low-tension breaker can be used in conjunction with a standard ignition coil. The secondary winding is connected directly to the fuelizer spark-plug. This plug is of special construction only in the electrode arrangement. A wide gap has proved to give the best results, the gap used being about 1/8 in. It has been found also that the amount of spark heat is of considerable importance, especially when starting up in extremely cold weather. In this respect the requirements are very similar to those demanded of the engine ignition system and, in general, the same type of coil windings can be used for both engine and fuelizer ignition service. If it were desirable to limit the current consumption to a minimum, a special coil having many more primary turns could be built for the fuelizer. The increased self-induction would result

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in a poorer spark at high speed, but this would not affect the fuelizer operation materially, since its main purpose is to supply heat at the lower speeds. Another method of securing the fuelizer spark consists of bringing out the inner end of the secondary winding of the regular ignition coil. Normally, this terminal is connected to ground either directly or through the primary winding. It is believed that such a method does not represent good practice, since the wide gap of the fuelizer plug offers considerable resistance when the throttle is wide-open. Under these conditions the compression pressure in the cylinders is at a maximum and therefore the resistance of the entire secondary circuit, including both the engine and fuelizer spark-plug in series, would be excessively high. Another method is to connect two ignition coils in series with a single breaker. One of these coils is connected to the fuelizer and the other to the engine ignition distributor. A fairly good result is attained in this way, provided the different elements of the system, such as the cam contour, the condenser and the coil windings, are suitably proportioned.

When magneto ignition is used, a special magneto is required. For four-cylinder installations, several types of five-spark magneto are available. In one type the rotor and interrupter are of eight-cylinder design, four sparks per revolution of the rotor being produced. Two of these go to the engine spark-plugs and two to those of the fuelizer. This system permits using only the negative sparks for engine ignition, which has certain advantages from the standpoint of spark-plug-electrode life. Another means of obtaining a magneto spark for the fuelizer is by insulating both ends of the secondary winding, which is commonly done in two-spark magneto construction.

Generally speaking, the requirements for the fuelizer ignition are similar to those for regular ignition. It is of advantage to have not less than two fuelizer sparks per revolution of the engine to assist in starting. Once the flame is established it will continue without the aid of a spark until such time as the throttle is suddenly opened. However, in practice it does not seem worth while to cut off the spark while the engine is running, although it is obvious that a simple thermostatic control could be worked out for this purpose. The spark-plug is of conventional construction except for the electrode, and this can be constructed in any manner desired without

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the restrictions imposed by preignition on regulation spark-plug design.

THE FUELIZER VS. HOT-SPOTS

The question may arise as to the comparative merits of the hot-spot and the fuelizer. By hot-spot I mean any of the exhaust-heated manifold-designs in which the heat is more or less localized. I believe the best answer is that the fuelizer covers a wider range of actual service, but that the fuelizer in conjunction with a judicious use of additional heat from either the exhaust or a suitable water-jacket offers the best solution. The average exhaust-heated manifold warms-up quickly if the throttle is opened when starting off; that is, if the engine is raced or if the car is run in low gear for a short distance. The fuelizer, on the other hand, operates to the best advantage when the engine is idling or operating under a reduced load. Under ordinary driving conditions the rate of mixture-temperature increase will be very much more rapid with the fuelizer. In exceptional cases, such as starting off cold at the base of a long hill, the exhaust-heated job may have the advantage, since this wide-open-throttle condition automatically cuts down the action of the fuelizer. A combination of these two systems covers every conceivable driving condition. Of course, as pointed out elsewhere, the application of the exhaust heat must be carried out carefully so as not to reduce the volumetric efficiency of the engine under wide-open throttle. In actual practice a suitably designed water-jacketed manifold gives excellent results in conjunction with a fuelizer, and this is of particular advantage in engine designs in which the intake-manifold is on the side opposite to the exhaust-manifold. Another point in favor of the fuelizer is that its design requires the least amount of metal exposed to a high temperature. When driving requirements change suddenly from light load to full load or vice versa, a suitable mixture temperature is arrived at very much more quickly with the fuelizer than with any exhaust-heated system. With this latter construction there is necessarily a greater mass of metal to cool off or heat up than with the fuelizer, and the time required to arrive at the desired temperature is necessarily prolonged.

The all-important advantage of the fuelizer over any exhaust-heated system is that it supplies the heat in exactly the amount needed to meet average driving con-

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dition. If an exhaust-heated manifold is made to give the mixture anything like the heat demanded for good idling and slow-speed work in cold weather, it will heat the charge unduly on a stiff pull on a hot day. This will result in a decreased power output of the engine and also an increase in heat loss to the jacket water which in turn requires great heat-dissipating ability on the part of the radiator.

What the fuelizer accomplishes under various conditions of operation is summarized as follows:

(1) In starting, it generally comes into operation even before the engine starts firing; this is especially noticeable in severely cold weather. The fuelizer is therefore of real service in insuring a prompt start

(2) For warming-up, if the engine is allowed to idle for a few moments the fuelizer heats the manifold very quickly. Even in severe weather, when driving away immediately after starting up, the engine will fire regularly within a very short distance

(3) For hard pulling, dynamometer tests show absolutely no difference in power when running wide-open with the fuelizer connected or disconnected. It is obvious that, since no heat is supplied by the fuelizer under these conditions, there can be no loss in volumetric efficiency

I have endeavored to show that the fuelizer furnishes the proper amount of heat to the intake-manifold under all conditions of running. This is accomplished in a very simple manner, particularly in some of the later designs, demanding practically no added complication to the engine except an extra source of ignition current which can be synchronized with the regular ignition current so as to form, if desired, a reserve system of engine ignition for emergency.

THE DETROIT DISCUSSION

U. G. THOMAS:—How much gasoline does this fuelizer save?

L. M. WOOLSON:—That depends upon the driver. Recent tests show that if the fuelizer is operated to the best advantage and the mixture is made suitably lean, a substantial increase in gasoline mileage should be attained. It is difficult to persuade drivers to pay any attention to carbureter adjustment, assuming that there is some kind of dash adjustment. The average driver will pull out the choke to start and probably leave it in that position

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unless something happens to call his attention to it. In certain cars weighing about 3400 lb. we have consistently obtained 21 miles per gal. of gasoline with the fuelizer. We might obtain just as good or better mileage without the fuelizer in warm weather. The figure I have given refers to average driving mostly in winter. The advantage of the fuelizer is that it enables the engine to run with the leanest possible mixture. If the driver does not take advantage of this, it is of course of no avail. I hope we shall have carbureters that require no attention from the driver, these being controlled thermostatically or automatically in some other way. With such carbureters we could get increased mileages. On a certain car equipped with the fuelizer, the test results were 15.6 miles per gal. when running without the fuelizer, and 15.3 miles per gal. when running with it. The carbureter adjustment was the same in both cases. When running with a fuelizer, a much leaner mixture can be used; it is difficult to state off-hand how much gasoline that would save. I believe that if the mixture were made lean as soon as the fuelizer began its action, at least 15 per cent of the gasoline could be saved.

H. S. BENJAMIN:—Fig. 3 shows a rise in temperature of the intake-manifold and the exhaust, and that the intake had a more rapid rise in temperature than the exhaust. If the exhaust-manifold could be made of aluminum, what would be the comparison in the rise in temperatures?

MR. WOOLSON:—It would be far more favorable, but the ultimate temperature for idling would be very much greater in any case. We have measured temperatures on the fuelizer-jacket walls of 800 deg. fahr. after a few minutes of idling; for instance, at the spreader of the V-type installation. The exhaust pipe never reaches any such temperature except when running with fairly wide-open throttle.

MR. BENJAMIN:—What is the temperature inside of the intake-manifold during idling?

MR. WOOLSON:—It will vary. With a water-jacket it probably will never go much beyond 220 deg. fahr. because the heat conductivity of the water prevents further temperature rise. In the single-six installation the temperature will go very much higher under prolonged idling because the apparatus is bolted directly to the exhaust pipe and the intake passages are formed partly integrally; probably 330 deg. fahr. would be reached in time.

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MR. BENJAMIN:—Do you not find that the heaviest portions of some motor fuels do not vaporize uniformly at 450 deg. fahr.?

MR. WOOLSON:—We should not confuse the end-points of fuels with the temperatures required for effecting complete vaporization in a 15 to 1 mixture. Under sub-

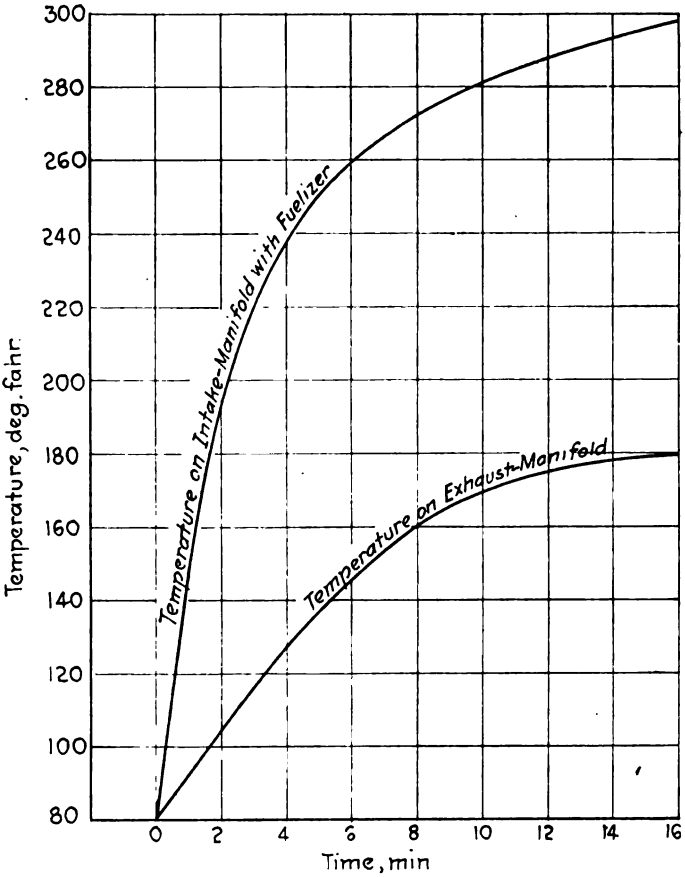

FIG. 3—CURVES SHOWING THE INCREASE IN TEMPERATURE ON THE OUTSIDE OF AN INTAKE-MANIFOLD EQUIPPED WITH THE FUELIZER OVER THAT ON THE OUTSIDE OF THE EXHAUST-MANIFOLD

atmospheric conditions as obtained in a manifold, nothing like a 450-deg.-fahr. temperature is needed to get a dry mixture.

MR. BENJAMIN:—That is true. I had crankcase

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dilution in mind. A certain part of the fuel will get past the piston-rings and cause dilution. If the temperature in the manifold is about 280 deg. fahr. and the end-point of the fuel is 450 deg. fahr., there will be a certain amount of crankcase dilution.

MR. WOOLSON:—That would occur only if the fuel were in a saturated atmosphere.

PROF. O. C. BERRY:—Tests at Purdue University show that Mr. Woolson's point is correct. We use a piece of metal about 3 in. wide, 10 in. long and ¾ in. thick, with a slight depression in the top. Fuel is syphoned over into that depression. There is a heating element under the metal and holes are drilled alongside the depression, so that the temperature of the metal to which the gasoline or fuel is exposed can be determined. The results reported are the number of minutes required to vaporize 0.01 lb. of fuel from 1 sq. in. of heated surface. At 300 deg. fahr., about 7 min. is required to vaporize completely 0.01 lb. of Red Crown power gasoline on 1 sq. in. of heated surface and this grade of gasoline has an end-point of 450 deg. fahr. The correct mixture, as Mr. Woolson stated, has just enough gasoline to use up all the oxygen at 15 lb. of air for 1 lb. of gasoline. With a value of three for the gasoline vapor, we have 45 volumes of air to 1 volume of gasoline vapor; so, the partial pressure on gasoline is only 1/45 of atmospheric pressure. Although the temperature of this room is less than 212 deg. fahr., the boiling temperature of water, the water vapor in the room would create a pressure of something like ½ in. of mercury; that is, it is possible to have the vapor present in the atmosphere at a lower temperature than corresponds with the boiling point of the liquid. We had a clean dried-off surface at a temperature considerably less than that of the end-point of the fuel for that reason.

T. J. LITLE, JR.:—When using a rather lean mixture, did not the flame retreat into the interstices of the gauze at the upper part of the fuelizer and burn it? We experienced that trouble in the development of Welsbach-light burners, particularly with pressures such as occur in burning gasoline, kerosene, distillates, alcohol and the like. What is the extent of dilution incidental to the introduction of that much burned charge directly into the intake-manifold?

MR. WOOLSON:—We originally used a 40-mesh screen. A lean mixture would burn a hole, frequently within 400

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to 500 hr. But with the mesh we are now using, the heat conductivity of the aluminum body of the burner is sufficiently great to prevent any such action, no matter how lean the mixture is. We have run these for 2000 hr. and none of the screen was consumed. Regarding the effect of the dilution caused by the burned gases, there is a strange phenomenon that many people do not recognize. There is absolutely no effect that is noticeable to the driver. There is about a 10-per cent dilution at very slow speed, but the engine can be idled at a slower speed with the fuelizer than without it. In the Van Blerck installation, it is almost impossible to stall the engine. As a matter of fact, at ½ m.p.h. there is no noticeable effect as regards dilution; the idling is not affected. The only evidence of the presence of the dilution would appear upon disconnecting the fuelizer and letting the mixture that was burning in the fuelizer join the main mixture. In that case the engine would speed up slightly, because it would be getting slightly more mixture than before.

MR. LITLE:—My understanding is that the charge from the burner enters the intake-manifold through small orifices. Do small projections of flame enter the screen and cause back-firing?

MR. WOOLSON:—We feared much trouble from this but have had none. The orifices must be far enough away from the burner body and the gases must be made to take a circuitous path if necessary. On an installation like that on the V-type engine, we use 3/16-in. diameter orifices. We have never experienced back-firing, but if the openings were increased to ¼-in. diameter there would be occasional back-firing.

PROF. BERRY:—It seems that in starting an engine in cold weather with the present grade of gasoline, if the temperature is too low, not enough gasoline is vaporized to support combustion and it is almost impossible to get ignition in the cylinder. Is the temperature below which we cannot go very much lower with the fuelizer than without it?

MR. WOOLSON:—The lowest temperature at which I have experimented with this device is about 10 deg. below zero fahr. We obtained very prompt ignition in the fuelizer burner body. We found we had ample heat in the spark there; it is only a matter of obtaining enough heat to start.

J. H. HUNT:—There is no such thing as a critical temperature, but the problem becomes progressively difficult.

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I think it is not caused entirely by the condition of the gasoline; I think the trouble is in getting the fuel to the place where we want it. The cranking speed is reduced greatly. Is there any specific figure for the amount of fuel that should be consumed in the burner, as compared with the amount of fuel that the engine is using when idling? Is there a ratio that could be applied, in going from one design of engine to another?

MR. WOOLSON:—That can be computed mathematically from the specific and latent heats. I believe a desirable increase of mixture temperature is something like 100 deg. fahr. To raise the temperature of the air and that of the fuel 100 deg., and completely vaporize the latter, something like 2 per cent of the British thermal units of the fuel dealt with must be consumed in the burner. The efficiency of the proceeding is fairly high. It is a kind of self-contained boiler proposition. It operates at something like 90-per cent fuel efficiency; so, it is simply a matter of what condition it is desired to meet. In arriving at the various calibrations we used common sense, not trying to go to extremes. We did not endeavor to melt the manifold, although that can be done. On an engine of about 400-cu. in. displacement, certainly not more than ½ pint per hr. should be burned at any time.

MR. HUNT:—What I referred to is more a matter of experiment than mathematics, because it is very certain that we want to use more than 2 per cent of the fuel that the engine requires when idling. We are not satisfied with simply a 100-deg-fahr. rise to get a quick result.

MR. WOOLSON:—That is all a matter of the standard set. A 100-deg-fahr. rise is considerable. It might not do for extreme conditions, but when we build apparatus like this, we try to meet average conditions. In connection with this fuelizer we try to make it as simple as possible; no matter how simple it is there is enough cause for trouble. If enough heat were used to serve at 30 deg. below zero fahr., certainly some control would be needed to shut it off in summer, which would involve complication. By adopting a middle course, giving sufficient heat for the average result, we satisfy everybody, I believe, and avoid creating too high a temperature in summer. The device permits, however, the use of as much gasoline as one cares to burn. I have never found any limitations.

MR. LITLE:—Is not the greatest value of this fuelizer the heating of the manifold quickly? That is its greatest

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function, I should say. With a cold engine in winter one gets under way very quickly.

MR. WOOLSON:—Yes.

MR. LITLE:—Instead of burning ½ pint per hr., why not burn 1 qt. per hr., and then cut it off? Would it not be desirable to get under way more quickly?

MR. WOOLSON:—That would mean some sort of manual control. We wanted to avoid that. The average car is used for fairly short hauls in winter. The opportunity for cutting the fuel supply off would probably not present itself very often on a cold winter day. It would not be desirable to cut it off for 2½ or 3 miles. I question whether it would be worth while to make provision for the occasional driver. The device is actuated very easily by opening the ignition circuit, although the throttle has to be stepped on to extinguish the flame. Opening the ignition circuit would form a certain and practical way of controlling the action.

MR. BENJAMIN:—Is not the apparatus arranged to shut off at a certain intake temperature?

MR. WOOLSON:—It does not respond to temperature influences, but only to depression influences.

MR. BENJAMIN:—But as the throttle is opened the temperatures increase and the fuelizer shuts off.

MR. WOOLSON:—That is a fortunate incident. As the throttle is opened, no more heat is needed and, as the compression pressure increases and the amount of suction decreases, less mixture is pulled through the fuelizer and less is burned. Consequently, the heat decreases; but the response is to manifold depression only, and not to any other influence.

A MEMBER:—Fig. 4 shows that there are two sources of heat. The incoming gas receives heat from the exhaust jacket on one side of the fuelizer; the other source is the exhaust gases from the fuelizer that enter the manifold itself. Which source is considered the more beneficial?

MR. WOOLSON:—The benefit from one source equals that from the other. When starting cold the direct contact of the heated gases of the mixture undoubtedly helps for the first few seconds. On the other hand, when accelerating, it is very desirable for best results to have very high mixture-temperatures. The heat that is stored in the metal comprising the fuelizer body is then relied upon. At low mixture-velocities the gasoline tends to

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hug the walls, deposit on them and creep up slowly. By having the walls hot, that effect is prevented.

A MEMBER:—What is the temperature of the gases that come in through the orifices in the fuelizer body itself?

MR. WOOLSON:—I cannot give accurate information regarding that. The temperature in the burner body is about 1000 deg. fahr. and where the burned gases in entering join the main gases they may have dropped 200 to 300 deg. fahr. during their passage. That is a fairly accurate statement. We have never put on thermocouples, because we thought that this was not necessary.

MR. HUNT:—The temperature of those gases is well over 2000 deg. fahr.

MR. WOOLSON:—When using aluminum bodies? How is that?

MR. HUNT:—The gases are cooled by the mixture on one side, or the device would not be possible. I refer to the flame immediately below the plug. The theoretical temperature, assuming that the specific heat of the air remains constant, is well up to 3000 deg. fahr.; we know it is above 2000 deg. fahr. until after it has been chilled, for we have actually measured the temperature of the flame.

MR. WOOLSON:—As a rule we use a cooler mixture that is somewhat too rich. We do that to get quick starting. A perfect flame would be colorless or very light blue and extremely hot. The flame we generally use is somewhat greenish in color. It probably contains a considerable amount of carbon monoxide. When running with a very lean mixture the heated electrode becomes red-hot, but not when running in the usual way.

MR. HUNT:—The pipe on your demonstration outfit is bright red. The temperature of the plug does not show the temperature of the flame.

MR. WOOLSON:—Not altogether. The point of maximum heat is determined by the richness of the mixture. A lean mixture will tend to burn up near the top of the flame. The rich mixture will tend to burn further down.

PROF. BERRY:—The statement has been made that the fuelizer is not so necessary for wide-open-throttle running as for starting up. As I understand it, the assumption is that under wide-open-throttle conditions there is better distribution through the manifold. I observed an engine under test conditions that did not seem to confirm this. It idled well and under throttled conditions at

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almost any speed seemed to give very good performance. But at high speed and wide-open throttle, it continued to miss; we could not find any carbureter adjustment that would cause every cylinder to fire regularly. That was puzzling to us, because we were not expecting poor dis-

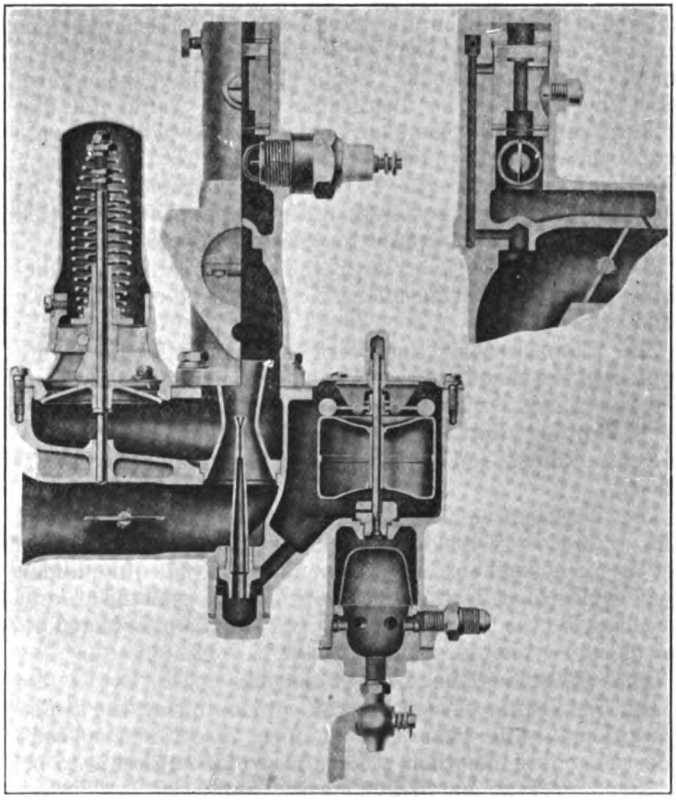

FIG. 4—AN APPLICATION OF THE LATEST TYPE OF FUELIZER TO A SIX-CYLINDER PASSENGER CAR

tribution under conditions of that kind. Finally, we substituted a good manifold from another engine and the trouble was eliminated. I am satisfied that the missing under the high-speed conditions of wide-open throttle was due to very poor mixture distribution in a cold manifold, even under those high-velocity conditions. Has Mr. Woolson made any experiments showing that at high speed there is better distribution of the liquid than at low speed, or whether the better engine performance is

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due to the fact that with high compression there can be a very much more poorly mixed charge?

MR. WOOLSON:—I qualified my statement that heat is not needed under wide-open throttle conditions, by stating that this applies only with a suitable manifold design. It is much easier to design a manifold that will give reasonably good distribution under wide-open throttle conditions than to design one that will give perfect distribution under idling conditions. Some engines have been built with the manifold so unsuitable that it would not distribute properly. Some airplane engines will generate more power under partial throttle, due to the stirring effect on the mixture. I think that problem can be attacked very much better by designing another manifold than by stifling the engine by heating up the charge.

PROF. BERRY:—Even with the best manifold, something is lost by cutting off heat at the wide-open throttle conditions.

MR. WOOLSON:—If that were the case, it would surely appear in the economy runs made at various temperatures. We ran a great many, with temperatures ranging from 90 to 212 deg. fahr.

PROF. BERRY:—Was that while using aviation gasoline?

MR. WOOLSON:—Yes, but aviation gasoline at 90 deg. fahr. is not very tractable; the fuel efficiency in pounds per horsepower-hour shows as nearly a flat line under those conditions. If the distribution were assisted to any material degree by the heating, it would be reflected in better fuel economy, would it not?

PROF. BERRY:—I believe it would be.

MR. WOOLSON:—Another way of looking at the problem of supplying heat at wide-open throttle is to consider what is done when a certain size of engine is to be designed, such as one of 200 cu. in. That size is selected because it is thought to be the smallest that will develop 50 hp., but the only way 50 hp. can be obtained from that size of engine is by keeping the mixture fairly cool. If the mixture is kept heated, the size of the engine must be increased; so I see no point in adding heat. The kerosene engine is a different proposition.

CHAIRMAN EARL G. GUNN:—Everyone who has had anything to do with engine design has certainly experimented with the heating of intake-manifolds in some manner or other. What is the effect of the fuelizer on a smoky exhaust?

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MR. WOOLSON:—On a cold day an engine not equipped with a fuelizer will emit considerable kerosene smoke if opened up after prolonged idling. The same engine equipped with a fuelizer can be idled indefinitely and will open up clean. Much of our experimenting was done in the summer. We built a box around the manifold and filled it with cracked ice and calcium chloride. It produced fairly good results. Mr. Hunt can drive a car into the laboratory refrigerator room for experimental purposes, and that is the ideal way.

MR. LITLE:—After the engine has been in the refrigerator room, say for 24 hr. at 10 deg. below zero fahr., within how many seconds will the engine start?

MR. WOOLSON:—We made a test at about 5 deg. above zero, which was as low as we could get at the time. That particular engine started within 8 sec. The fuelizer started almost instantly. The engine was able to run idling in the refrigerator room within 20 sec. with the summer setting on the air-valve.

MILTON TIBBETTS:—It appears to have been taken for granted that everyone knows what results have been given with the fuelizer as regards crankcase dilution and spark-plug fouling. What are the actual results along that line?

MR. WOOLSON:—I have never seen or heard of an engine on which a fuelizer was operating that ever fouled a spark-plug. That covers an experience of 18 months with several thousand cars. I believe that a spark-plug could not be fouled under ordinary driving conditions on a car equipped with a fuelizer; the porcelain might break, the electrodes might burn off, or something else might happen, but the spark-plug will never foul in the accepted sense of the word. As to what is achieved in regard to crankcase dilution, with the fuelizer in operation we do not maintain the viscosity of the oil at the original figure, because that is not necessary. But we keep the crankcase oil from building up in winter. The engine uses its regular amount of oil, and its viscosity is reduced somewhat in cold weather, but that does not matter. Not much dilution is required to reduce the viscosity slightly. One of the most needed accessories at present is some sort of simple viscosimeter. We tell the owner to test the oil, but he can do this only in a very crude way. Some efficient way of testing oil is required because much oil is wasted. Garages should be equipped to recover good oil from oil that is now thrown away.

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Many makers tell people to throw away the oil every 500 miles. That represents a considerable waste of the petroleum resources of the country; it must amount to several millions of gallons annually. Something ought to be done about it.

G. E. GODARD:—Have you made any tests to show what percentage of gasoline the oil contains when running with and without the fuelizer?

MR. WOOLSON:—We generally make these tests with weighing apparatus. We made many oil-consumption tests with the fuelizer and without it. This can be done on the dynamometer very well. The oil supply increases at a definite rate when running without a fuelizer, due to dilution. If the fuelizer is kept in action and a dry or nearly dry condition maintained, the difference is something like 4 oz. per hr. under idling conditions, with the water temperature at about 100 deg. fahr. While crankcase dilution is not entirely eliminated with the fuelizer, it is eliminated to such an extent that it is no longer a problem.

A MEMBER:—Will the manufacturer build a fuelizer adaptable to almost any car having a manifold such as that on the Ford car, and that will tend to eliminate all trouble?

MR. WOOLSON:—We have tried the fuelizer on many different makes of car. There was not a case in which we did not get better results.

MR. TIBBETTS:—Mr. Woolson and I have worked together on that and the Packard company has tried to cooperate with other manufacturers in this matter of adapting the fuelizer to various cars, particularly the old ones. So far we have not been able to do that. I do not know whether we ever will or not. It is a large problem.

THE CLEVELAND DISCUSSION

MR. WOOLSON:—Fig. 5 shows a cross-section of the fuelizer, which I will describe briefly. It has a conventional-type carbureter. The suction plugs are located above the throttle and have 3/16-in. holes. When the engine is running slowly there is a high suction that draws in a mixture of gasoline and air through the burner, where it is ignited. Heat is communicated to a portion of the manifold and the burned gases go down through the side walls. We thought we would encounter preignition. As a matter of fact, we observed flame coming out at these plugs and we had no difficulty with it

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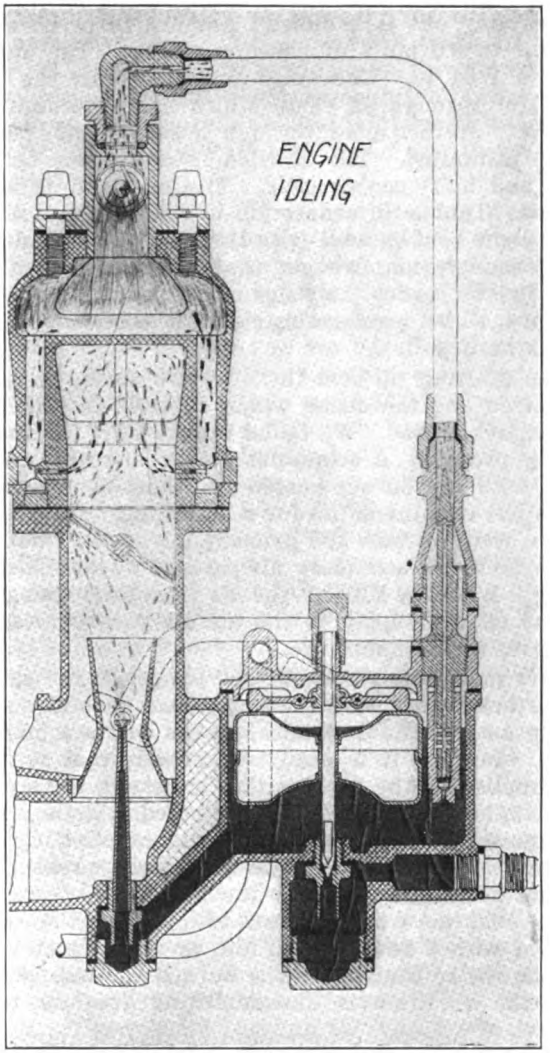

FIG. 5—CROSS-SECTION OF THE FUELIZER AS USED ON A TWIN-SIX PASSENGER CAR

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at all. It was easy to cool the mixture and so prevent premature firing. The small carbureter is built in the simplest way. It is a difficult problem to carburet say from 0.1 to 0.3 pints of gasoline per hr. The annular spray is 1/64 in. The mixture issues from the small carbureter through an elbow which has a peculiar construction. It then goes through a screen and, passing a plug, is ignited. The ignition is continuous between closed and half-open throttle. The manifold is water-jacketed. That is in connection with the desirability of having some heat on wide-open throttle. As regards heat during acceleration, we get that by having plenty of metal directly under the flame. That provides the heat necessary while accelerating, and it cools off rapidly under a hard pull.

When starting up cold the air-valve spring is highly compressed and the choke which controls the air is almost entirely closed. We found that to start the fuelizer burning promptly a somewhat richer mixture was required until the burner heated-up. That sounds simple enough but it bothered us for a long time. To make the mixture rich, we take the primary air of the small carbureter from the secondary air-passage of the main carbureter. When we shut off the air from this passage, we also cut off the supply to the auxiliary carbureter. It then gives a richer mixture.

I have made many tests at low temperatures, such as 10 deg. below zero fahr. The fuelizer generally starts burning an appreciable time before the engine commences to run. In fact, it is easily conceivable that it is the heat supplied by the fuelizer that assists in the starting of the engine. In Fig. 5 it will be noted that the burned gas joins the main mixture at two places. Getting equal distribution of the burned gas presents a problem, but it is not a difficult one. We thought, with others, that there would be trouble when idling, but the engine equipped with a fuelizer will idle as well, if not better. than one not so equipped. The burned gas is practically inert; the condition is like admitting free air to the mixture.

K. B. BRITTON:—Is there complete combustion?

MR. WOOLSON:—That depends largely upon the quality of the mixture. We have made no exhaust-gas analysis. We can tell by the color of the flame in the burner body design are known, it is easy to insure combustion body what kind of a mixture there is. We know that

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combustion is aided by having high compression but in the case of the fuelizer we are carrying on combustion in a partial vacuum. As soon as the tricks of burner-under all conditions. In a wide-open throttle condition, the volume of mixture drawn through the burner body is very slight. No appreciable heat is given off under wide-open throttle, because the amount of gas in the burner is limited.

The drawing at the left of Fig. 6 shows what conditions must be obtained to get combustion. It is important that the mixture be atomized and distributed evenly in the burner body; it is not effective to distribute it unless it is atomized. Atomizers for oil for fuel purposes are complicated in form; so we began designing atomizers. We hit upon the design shown rather accidentally, and we have not been able to make an atomizer work any better. A screen with a peculiarly shaped orifice is located at the top of the burner body. Certain shapes of orifice give the best results. The spark-plug has a loop terminal and a gap of ⅛ to 3/16 in. The theory is that any time an inquisitive mechanic takes out a plug with a wide gap, he will narrow it down and cause trouble. It is important to locate the spark in the right place. The best working condition is shown in Fig. 6. The glass inspection window has not given any trouble and offers an interesting opportunity to inspect the operation.

Two conditions of the simplified atomizer are shown at the center and right of Fig. 6. The hole in the central drawing is slightly off center. We test these holes by allowing a stream of water to pass through them. If they are not off center we get the effect shown at the right. There is a great difference between the operation of the two sprays. The screen is located at the proper distance below to straighten the spray out in the burner body. Incidentally, the small hole in the atomizing elbow prevents popping-back. We were bothered at first by popping-back; when combustion started, there would be a flare-back that made the pipe hot. That was solved simply. The velocity through the elbow was increased. That eliminates any popping-back tendencies. The hole is 3/32 in. in diameter on the Twin-Six engine.

Fig. 4 shows the later development of the fuelizer. The passage which communicates with the elbow is located in the correct place to pick off the right mixture. In our earliest experiments we tried to do that, but it is surprisingly difficult to pick off a uniform mixture

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from a carbureter of this type; a spotty mixture is obtained. But by experimenting we determined the design shown in Fig. 4, which gives uniform results. This design enables us to set a carbureter by the color of the flame in the fuelizer. The fuelizer will burn all kinds of mixture except the very richest. At the lean end, the fuelizer will burn a leaner mixture than the engine will run on. Through the glass shown over the burner body we are able to see the color of the flame. It is surprising how the color changes with the mixture. A perfect mixture is represented by a sky-blue flame; the electrode gets bright red. A rich mixture will give an emerald green color. In a very rich mixture, the liquid gas can be seen. This carbureter is somewhat unconventional in design in that the throttle is distant from the jet. Since we made this design we have been able to simplify the picking-off point and adapt it to a conventional carbureter of any make.

A MEMBER:—What mixture works best for idling?

MR. WOOLSON:—There is no way of determining that. The fuelizer can be adjusted to use mixtures varying from the richest to the leanest; there is no perceptible difference. The volume of gas is such a small percentage of the total that it does not affect the whole.

A MEMBER: — What percentage passes through the fuelizer when the engine is idling?

MR. WOOLSON:—At the most about 0.4 pint per hr.; about 5 per cent.

A MEMBER:—Is that for wide-open or closed throttle?

MR. WOOLSON:—At wide-open throttle very little mixture goes through the fuelizer.

A MEMBER:—What is the pressure drop at wide-open throttle?

MR. WOOLSON:—It may be from 1½ to 2 in. of mercury. I am not prepared to state accurately. On the other hand, there are many constrictions between the vaporizer and the burner body. There is no perceptible amount of flame with less than 6 in. of mercury depression in the burner body.

H. B. MASSEY:—What experience have you had at 10 deg. below zero fahr.? Will the fuelizer heat before the engine starts firing? Can its heating be depended upon?

MR. WOOLSON:—If the choke is pulled out it will invariably light. We paid particular attention to that.

MR. MASSEY:—At 10 deg. below zero, about how long does it take to crank the engine?

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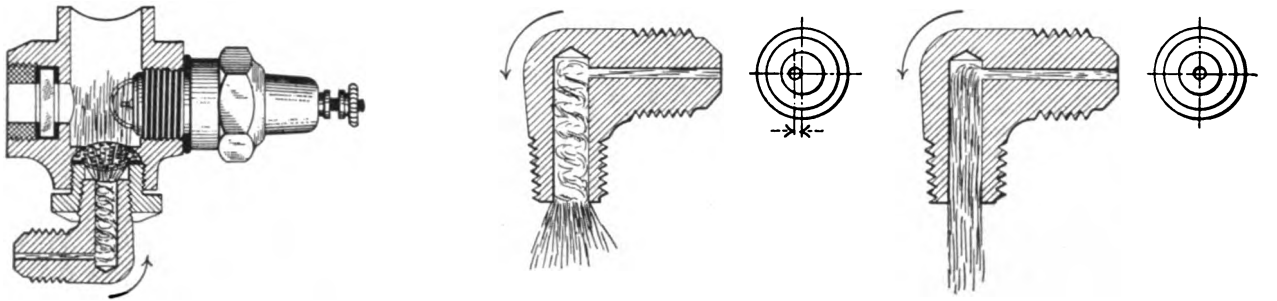

FIG. 6—SKELETON VIEW OF THE BURNER BODY AT THE LEFT. THE CORRECT FORM OF ATOMIZING ELBOW IN THE CENTER AND THE INCORRECT FORM OF ATOMIZING ELBOW AT THE RIGHT

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MR. WOOLSON:—About 3 sec.

A MEMBER:—How long will it burn with one spark?

MR. WOOLSON:—It can run without any spark. No spark is needed after starting, but a spark is necessary after sudden acceleration. In cold weather it is desirable to get all the heat obtainable.

A MEMBER:—What is the difference in mileage with and without the fuelizer, under the same conditions?

MR. WOOLSON:—I have made tests under flat running conditions. I obtained 15.5 miles per gal. without and 15.2 miles per gal. with the fuelizer; the difference is very slight. Under severe conditions, such as a series of accelerations, the improvement in acceleration due to the fuelizer will give better mileage with it than without.

A MEMBER:—If the acceleration were the same, would better mileage be obtained with the fuelizer than without it?

MR. WOOLSON:—Yes, acceleration is improved about 20 per cent by using the fuelizer and the pedal can be held down for a shorter length of time.

A MEMBER:—What percentage of the fuel entering the manifold is vaporized before reaching the cylinder?

MR. WOOLSON:—All I can say is that a sufficient portion is vaporized to give us what we need; it is of no advantage to go further, but we could increase the amount of heat.

A MEMBER:—What is the difference in carbonizing, with and without the fuelizer?

MR. WOOLSON:—Our claim for the results regarding carbonizing is based on the knowledge that we experience no spark-plug trouble. If the spark-plugs do not foul, it is reasonable to suppose that the carbon deposit is not formed. Detonation has more to do with the causing of carbon deposits than any other factor. Mr. Kettering, Mr. Horning and others are working on this problem. When we eliminate detonation, we will get rid of a main cause of carbon deposit. A deposit of the same depth of carbon with present-day fuels causes twice the spark knock that high-test fuels cause and this is responsible for the general complaint of carbonizing. This device takes care of carbon resulting from the burning of kerosene. There will be naturally more carbon in an engine using a wet mixture than in one in which the mixture is dry. We found we could run at least 1000 hr. and show no carbon on the fuelizer screen when the mixture was correct. If the mixture is rich, a carbon deposit occurs

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within 500 hr. and necessitates cleaning the screen. With a correct mixture it will burn clean indefinitely. That is the reason it is important to insure a correct mixture. The later forms of fuelizer show an improvement in that respect. It is reasonable to suppose that the driver will adjust his mixture control to obtain the best mixture.

A MEMBER:—If carbon is deposited on the screen, can it be burned off with a different mixture?

MR. WOOLSON:—No, but it can be scraped off. The screen may require cleaning every six or seven months, but with the correct mixture it will run indefinitely.

A MEMBER:—Does the heat transmitted through the fuelizer walls or that contained in the burnt gases do the most good?

MR. WOOLSON:—Both sources are used about equally.

A MEMBER:—Is there no volumetric sacrifice?

MR. WOOLSON:—Not with a wide-open throttle. As soon as the throttle is opened wide enough, the flame goes out.

A MEMBER:—Is there any difficulty due to oxidation of the screen?

MR. WOOLSON:—No, it is made of ordinary brass.

A. J. SCAIFE:—Is the screen used on the new design?

MR. WOOLSON:—Yes.

E. W. WEAVER:—I note the infiintesimally small hole for the passage of the gas. Does that hole become clogged?

MR. WOOLSON:—The only time it becomes clogged is during its manufacture. In the beginning we had to inspect it and supervise the washing process to get the chips out. It gives practically no trouble in the car. The bottom of the vaporizer is only ¾ in. below the level of the gasoline in the float-chamber; the remaining distance is 1½ in. The tendency is to keep particles away from that hole; furthermore, the gasoline is entering the float-chamber and 95 per cent is supplied to the main jet. There is every chance that the main jet will get the obstructions.

A MEMBER:—Is any trouble caused by dust?

MR. WOOLSON:—We have had no trouble from that source. We locate the air inlet where we think there is no dust. Many persons thought we would have trouble with dirt, but that has not been the case.

A MEMBER:—Can this fuelizer be applied when kerosene is used for fuel?

MR. WOOLSON:—I have run on kerosene repeatedly.

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It will run on kerosene, but I believe it cannot be made to start. It might be possible to start with kerosene by using electric heating methods, but the ordinary way is to start on gasoline and then turn on kerosene.

A MEMBER:—Can more heat be provided?

MR. WOOLSON:—Yes, but we are not doing that now.

A MEMBER:—If heat were supplied, would the fact that an inert gas is used cut down detonation?

MR. WOOLSON:—I think it would, but it is something that is associated with a wide-open throttle. That is the wrong way to kill detonation; it kills the engine power. It must be cured in a way that will increase the engine power.

A MEMBER:—What is the temperature of the gas in the manifold while idling?

MR. WOOLSON:—That depends upon how long the engine idles. It will get extremely hot in time. We have had so much heat on the manifold that the thermometer registered from 200 to 400 deg. fahr.

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DETROIT SECTION PAPER

UNDERLYING PRINCIPLES OF ELECTRICAL IGNITION

By Benjamin F Bailey[1]

The author uses some analogies of mechanical things to illustrate the underlying facts that must be considered in connection with electrical ingition, the first being that of an automobile starting under the influence of a constant force, which is analogous mechanically to the old touch-spark ignition circuit in that the velocity of the automobile corresponds with the velocity or speed at which the electricity is moving through the circuit.

In similar manner the analogy is extended to include car acceleration and its acquirement of a certain store of energy as an illustration of electrical-energy storage as the current through an induction-coil is increased; and further analogies are made, numerous diagrams being presented. Battery and magneto-ignition similarities are treated in a similar way, short and long sparks are discussed pro and con and spark lag is considered in general terms.

My purpose is to point out some of the underlying facts that we must consider in connection with electrical ignition. I shall try to make them plain by the use of some analogies with mechanical things. Let me

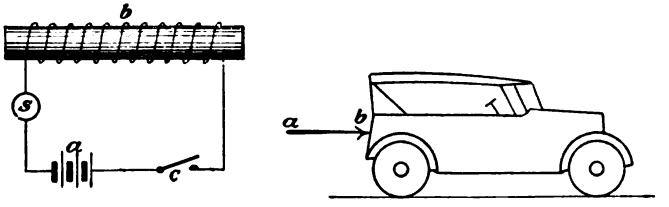

Fig. 1—Diagram of the Old Touch-Spark Ignition Circuit Which Is Analogous Mechanically to an Automobile Starting under the Influence of a Constant Force

speak first about the simplest form of electric ignition, one that is now practically obsolete but formerly was very common. Fig. 1, at the left, shows the circuit of the old touch-spark or wipe-spark ignition. A bat-

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tery is shown at *a*, a coil of wire wound around an iron core at *b*, and at *c* a contact-breaker which opens and closes. The iron core consists preferably of a bundle of iron wire. In this type of ignition that contact breaker is located inside of the cylinder and is opened and closed by the motion of the engine. There is also a switch *s* on the outside to turn the ignition off and on. There is a very close mechanical analogy between this circuit and an automobile starting under the influence of a constant force. At the right in Fig. 1 the car is being accelerated from rest by a force applied in the direction *a b*. This corresponds with the electromotive force applied by the battery to the coil.

In the electrical device we have current; in the automobile we have velocity. The velocity of the automobile corresponds with the velocity or speed at which the electricity is moving through the circuit. The mass of the car corresponds with what we call the inductance of the coil; and, lastly, the friction of the car corresponds with the resistance of the electric circuit. The car resists being moved on account of friction. Electricity resists being moved due to resistance. We have what we call inductance in the electric circuit. If an attempt is made to change the velocity of the car, the change is resisted by the inertia of the car. Similarly, any change in the current through a coil is resisted by the inductance of the coil. If the circuit be closed, a current passes through the coil and sets up a magnetic field. As the current grows it sets up lines of magnetism through the iron core. As these lines grow they induce in the wire an electromotive force which resists the rise of the current. The system is conservative and always resists any change. If the current is flowing it dislikes to stop and if it is not flowing it dislikes to start. In that respect it is exactly analogous to the automobile, which resists being started and requires brakes to stop it. This growth of the magnetic lines explains why we have an inertia effect in electric circuits. Applying a constant force to the car at the right in Fig. 1 would be analogous to applying a constant electromotive force to the coil at the left in Fig. 1. In the case of a car it will start, accelerate gradually and finally reach a certain definite limiting speed when the frictional resistance is just enough to balance the force. If we plot the curve of velocity and time, as in Fig. 2, it will rise and finally become horizontal. The final value will depend upon the frictional

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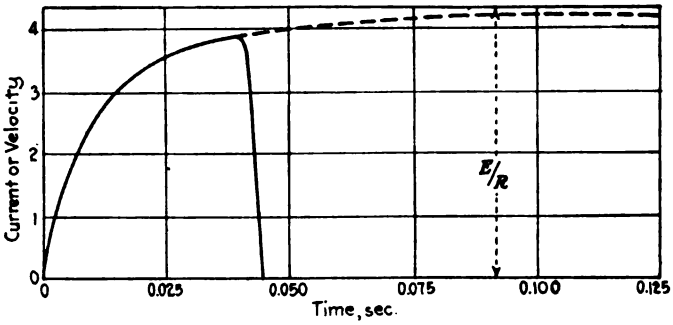

FIG. 2—CURVE SHOWING THE TIME RATE OF GROWTH OF AN ELECTRIC CURRENT OR THE VELOCITY OF A CAR ACCELERATING GRADUALLY

resistance and the force applied. In the case of the electric circuit precisely the same thing happens. The current starts, rises and gradually attains its final value, which is determined by the resistance and the electromotive force of the circuit. In the mechanical case we have the velocity finally equal to the force divided by the friction. In the electrical circuit we have the current, represented by I, equal to E/R. In neither case is the velocity or the current attained instantly. It takes time to do it. The exact expression for this curve is as follows:

$$I = E/R\ (1 - e^{-Rt/L})$$

in which

I = the current at any instant
E = the electromotive force of the battery
R = the resistance of the entire circuit
L = the inductance
t = the elapsed time following the closing of the circuit
e = the base of the Naperian system of logarithms

The instantaneous value of the current at any time is equal to the electromotive force divided by the resistance, multiplied by a reducing factor. As time increases the reducing factor increases, the value finally reaching unity. The current then equals the electromotive force divided by the resistance.

The analogy can be carried further. As we accelerate the car, we expend energy and the car acquires a certain store of energy. As we increase the current through the induction-coil we are similarly storing energy. The expressions in the two instances are again analogous. In the case of the car we know that the energy stored is

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equal to one-half of the mass of the car times the square of the velocity. In the electric circuit it is one-half of the inductance times the square of the current. The corresponding mathematical expressions for the stored energy are $\frac{1}{2} Mv^2$ and $\frac{1}{2} LI^2$. If we stop the car suddenly with the brakes, what happens? We increase the friction by putting on the brakes. In the case of the electric circuit, we have a similar thing. When we open the circuit that does not mean that we stop the current instantly, but we introduce the resistance of the air-gap which, comparatively speaking, gradually stops the current. The current in stopping follows a curve similar to that which the car follows while it is stopping. In either case the energy must be expended somehow. With the car the brakes get hot. In the case of the electric circuit the energy is expended in the gap and the gap gets hot; in other words we have a spark there which is capable of igniting a mixture of air and gasoline.

We also can extend the analogy to the force that is developed by the stopping. In the case of the car, if we try to stop it suddenly the force required is very great. If we stop it gradually, a much smaller force will suffice. In the case of the electric circuit, if we open up the gap rapidly there is a large induced electromotive force, just as though we had stopped the car suddenly, for instance, by a collision. The more sudden the stopping is, the greater the force will be. So, the more quickly the gap opens the higher is the electromotive force that will be developed. This system has become more or less obsolete, although it has great advantages in its favor. It is unquestionably the simplest device from the electrical standpoint, but the mechanical complications, such as the difficulty of keeping the points in order, have caused its disuse, except perhaps for large stationary engines.

A slight modification brings us near to what we have in the secondary coil, or the regular induction-coil. If we shunt a condenser across *c* in Fig. 1 we have the arrangement shown at the left in Fig. 3. A condenser is built up of a series of sheets of tinfoil or similar material, separated by an insulating medium. The current cannot pass through the condenser because of the insulating material between the plates. A certain amount of electricity can, however, be stored in a condenser. The amount is proportional to the force applied to push it in; in other words to the electromotive force.

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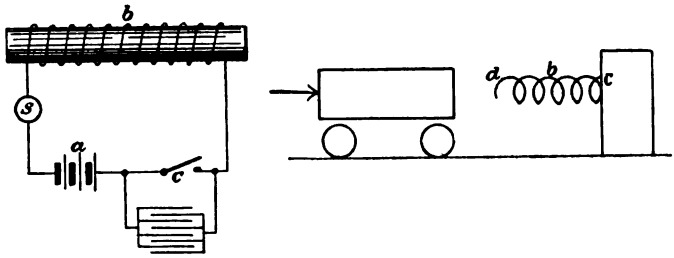

FIG. 3—DIAGRAM OF AN ELECTRICAL CIRCUIT IN WHICH A CONDENSER IS INTRODUCED AND THE CAR IS CONSIDERED TO STOP BY STRIKING A SPRING RATHER THAN BY APPLYING THE BRAKES

We can represent an analogous set-up in the case of our car. Instead of putting on the brakes, we will allow the car to hit the spring shown at *b* in the right portion of Fig. 3 which is fastened at the point *c* and loose at the point *d*. Closing the contact c at the left in Fig. 3 is analogous to giving the car at the right a push. Opening the contact *c* is equivalent to allowing the car to hit the spring in Fig. 3 and become attached to it. The

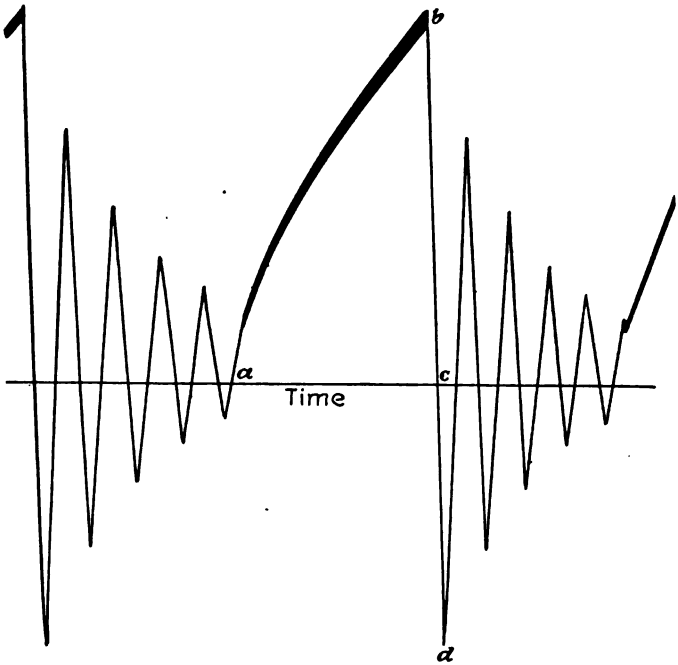

FIG. 4—DIAGRAM SHOWING THE OSCILLATION OF AN ELECTRIC CURRENT WHEN THE CIRCUIT IS OPENED

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analogy between the spring and the condenser is perfect. The distortion of the spring is proportional to the force applied to it and so is the distortion in the electric condenser; that is, the quantity of electricity that is stored in the condenser is proportional to the force applied to accomplish this result, just as the distortion in the spring is proportional to the force applied to it.

Suppose the car goes up against the spring at *b* and is coupled to it in some way so that it cannot get away. It will compress the spring, shoot back, go forward and keep oscillating until the friction finally brings it to rest as shown in Fig. 4. Exactly the same thing happens in the case of the electric current. We close the circuit, which corresponds to starting to push the car. The velocity increases as shown by the line *a b* in Fig. 4. At *b* we open the circuit, which is analogous to having the car hit the spring. The current is brought to zero rather quickly, but it swings past the zero value, increases to a negative value of *c d*, again decreases, reverses and so on, oscillating in this way for some time. We can control the frequency of electric oscillation in the same way that we can control the frequency of oscillation of the car, or just exactly as we can control the period at which a car bounces on the springs when it hits a bump. There is absolutely no difference between the two phenomena. If we want the oscillations of the car to be slow, we make it very heavy, or use very flexible springs, or do both. If we want them to be quick and sharp, we make the car lighter, or the springs stiffer. We do exactly the same thing in the case of the electric circuit. If we want the oscillation to be quick, we stiffen the condenser; that is, we use a condenser that will not store so much electricity for a given force, just as we stiffen a spring so that it will not deflect so much for a given force; in other words, we use a smaller condenser. Another way to quicken the oscillations would be to reduce the inductance of the coil *b;* that is, to reduce the property which corresponds to mass by putting fewer turns on it. We can go further and calculate the frequency of the oscillations, if we know the constants involved in the problem, just as we can calculate the frequency with which a car will oscillate when it hits a bump, if we know the weight of the body and other constants. As a matter of fact, these electrical oscillations generally require in the neighborhood of 1/3000 sec.; that is, there will be about 3000 complete oscillations in each second.

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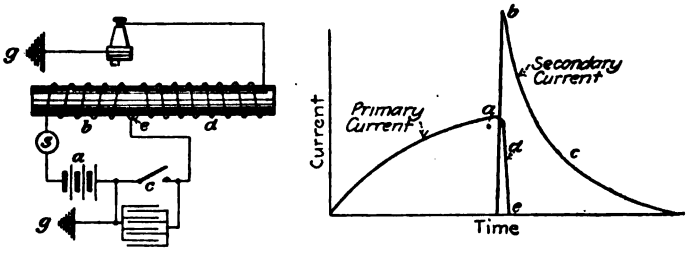

FIG. 5—DIAGRAMMATIC VIEW OF A TYPICAL IGNITION CIRCUIT IN USE AT THE PRESENT TIME AT THE LEFT AND AT THE RIGHT THE CURVES OF PRIMARY AND SECONDARY CURRENT

To modify the simple diagram shown at the left in Fig. 3 and make it correspond with the coils that we actually use today, we put a secondary on the coil as shown at the left in Fig. 5. The secondary winding is usually wound over the primary winding, but is drawn separately to simplify the diagram. If we close the circuit at the left in Fig. 5, the current will rise in the primary of the coil. This means that the magnetic lines will increase in number in the coil, starting from zero. This will induce electromotive force in the secondary of the coil, at the "make." However, the rise is fairly slow. The electromotive force induced is dependent on the rate at which the magnetic lines are cut. If we cut the lines slowly, the electromotive force is small; if we cut them fast, it is high. Hence, the electromotive force that we get in the secondary of the coil is comparatively small. It is small enough that the spark cannot jump the gap on the spark-plug. If we had no spark-plug, we would have the current flowing in the secondary at the make but with the spark-plug there we get no current if everything is all right. When we reach the point *b* in Fig. 4 and open the circuit, if the condenser is properly adjusted, the rate of cutting of the magnetism will be exceedingly rapid, and consequently a very high electromotive force be induced. If no current flows through the circuit, for example, if the wire is detached from the spark-plug, the primary current will continue to oscillate, just as it did without any secondary winding on the coil, and we shall have an oscillating secondary electromotive force. But ordinarily that is not what we get or what we want. As a rule, we have enough electromotive force in the secondary so that the current jumps across at the spark-plug gap at the left in Fig. 5. In this case we have little or no oscillation. It is perhaps difficult to understand why

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this is so but, as soon as the spark jumps, it begins to absorb the energy that was stored in the electric circuit. The action is the same as that which takes place in a car equipped with shock-absorbers. The friction resists the motion, absorbs the energy and therefore kills out the oscillation that we would otherwise get. So, in the electric circuit, if we put in a resistance and allow the current to do work, if the resistance is low enough it will kill the oscillation entirely; the current then comes down to zero and stops there. Practically, we never succeed in transferring all the energy from the primary to the secondary of the coil. We always have some oscillation left. The curves of primary and secondary current are shown at the right in Fig. 5. The secondary current is much smaller than the primary, but is here plotted to a larger scale to make the diagram clearer.

What happens in the secondary is exactly what will happen if we have our car in motion, shut off the driving force and allow the car to coast. It will slow down gradually until it comes to a stop, and follow a curve very much like the curve of the secondary current, shown at the right in Fig. 5. The primary current is large; in an average coil it would amount to from 2 to 5 amp. at the point *a*. In the secondary the current at *b* would be perhaps 0.1 amp.

Curves like those of Figs. 2, 4 and the one shown at the right in Fig. 5, are obtained by an oscillograph. The oscillograph is an ammeter with the parts made so light that they can keep up with the very rapid fluctuations of the current. When the current fluctuates very rapidly through an ordinary ammeter, the needle does not have time to follow and it will simply stand still and indicate an average value. In the oscillograph the moving parts are exceedingly light and have so high a natural period of oscillation that they can keep up with any ordinary variation. A very small mirror reflects a beam of light against a moving film and traces out its path along the film.

In the actual ignition system some other points must be taken into account. Fig. 6 shows the curve of rise of current in an induction-coil. We do not always get the same distance along that curve. If the car is standing still and the breaker-points on the ignition switch are closed, the current reaches the highest possible value which is E/R. But when the engine is functioning and the breaker-points are opening and closing rapidly, there

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will not be time enough to get full current value. If the engine is running slowly, we get say the value shown at *a;* if it is running twice as fast, we get the value shown at *b*, and if four times as fast, we get the value shown at *c*. The energy we have stored in the coil is equal to $\frac{1}{2} Li^2$ or one-half the product of the inductance and the square of the current, just as the energy stored in a moving car is $\frac{1}{2} Mv^2$. This means that we will not get anywhere near so much out of the coil at high as at low speed, because the contact is not closed nearly so long.

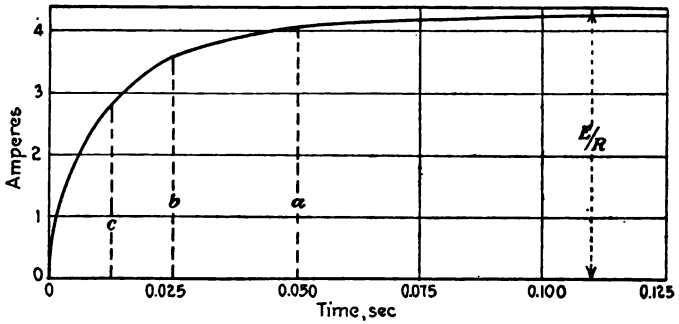

FIG. 6—CURVE SHOWING THE RISE OF CURRENT IN AN INDUCTION COIL

Thus it will be seen that the faster the engine is running the less will be the energy stored in the coil each time the contact is closed. The energy delivered is less than the energy stored, but can be taken as roughly proportional to it. In Curve *I* of Fig. 7, the values of the energy per spark with the revolutions per minute of the engine are plotted. This curve is of course derived from Fig. 6. Its exact shape depends upon the characteristics of the coil, the number of sparks per revolution and the percentage of time that the breaker-points are open. The design must be such that the ignition is satisfactory at the highest possible speed of the engine. At the lower speeds the spark will then be somewhat stronger than is absolutely necessary.

BATTERY AND MAGNETO-IGNITION SIMILARITIES

The modern high-tension magneto has an induction coil with primary and secondary windings. The primary is short-circuited most of the time by contact points which open when the spark is to be produced. These points are shunted by a condenser. So far we have everything that we have in the battery system, except the battery. I said an

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induction-coil; it is actually called an armature, but it is the same thing, practically. It consists of some laminated iron around which two coils of wire are wound; one coil is of comparatively coarse iron wire, and the other is of very fine wire. In that sense it is an induction-coil. Including the breaker, we have all the elements of the battery system, except the battery itself. We substitute for the electromotive force of the battery the electromotive force which is generated directly in the primary coil by the rotation of the magneto armature. The electromotive force generated by the armature of the magneto is an alternating one and not the steady, direct, electromotive force furnished to the induction-coil, because the magnetic flux is cut first in one direction, and then in the opposite direction, generating a to-and-fro electromotive force instead of an electromotive force in one direction. The fact that the current is alternating does not bother us particularly, provided we break it at or near the time it has its maximum value. If we should break it when it is down near zero, we would not get much of a spark, but if we break the current when it is near the top of its wave, the conditions are very much the same as in the case of the induction-coil system.

One point of difference which is rather insisted upon by the makers of magnetos is the fact that in the secondary we have not only the electromotive force which has been induced by the very rapid dying down of the primary current, but we have the electromotive force which is due to the cutting which continues after the points are open. The curve at the right in Fig. 5 shows how the primary current rises and then drops very suddenly, and how the secondary current rises very quickly and then tapers off. After the circuit has been broken, the secondary current is left entirely to itself. It is like a car that has been given an impulse, left to coast and finally comes to rest. That is not true with the magneto. We keep on applying a push to the electric circuits, just as though we had the clutch partially in on the automobile and applied a slight push instead of allowing it to coast freely. This is because we keep on generating electromotive force. The result is that the secondary magneto-current does not die down so rapidly as that from a coil. This effect is the so-called follow-over. It is the current which the magneto men say produces the "whiskers" on the spark.

We can now compare the current we get from the mag-

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neto with that we get from a battery-ignition system. The electromotive force in the magneto is supplied by its rotation. Obviously, if the magneto is standing still, there will be no electromotive force. Obviously also, as it speeds up, the electromotive force increases in proportion; so we have very much the same condition as if we had a battery-ignition system in which we started with very low electromotive force at slow speed and gradually increased it in proportion as the engine ran faster. Hence, instead of giving a constant push we give it a much harder push at the higher speed. The current in the magneto rises along very much the same curve as is shown in Fig. 6, but the steepness of the curve depends upon the speed of rotation of the magneto. The higher the speed is, the more rapid is the rise of current but, on the other hand, the shorter is the time during which the current is allowed to run. The result is that the energy per spark increases with the speed, but not so fast as we might expect. In fact, there may be an actual drop in energy per spark at very high speeds. Curve *M* of Fig. 7 shows approximately what happens. Obviously, neither of the curves of Fig. 7 represents ideal conditions. If the battery spark is strong enough at high speeds, it is too strong at low

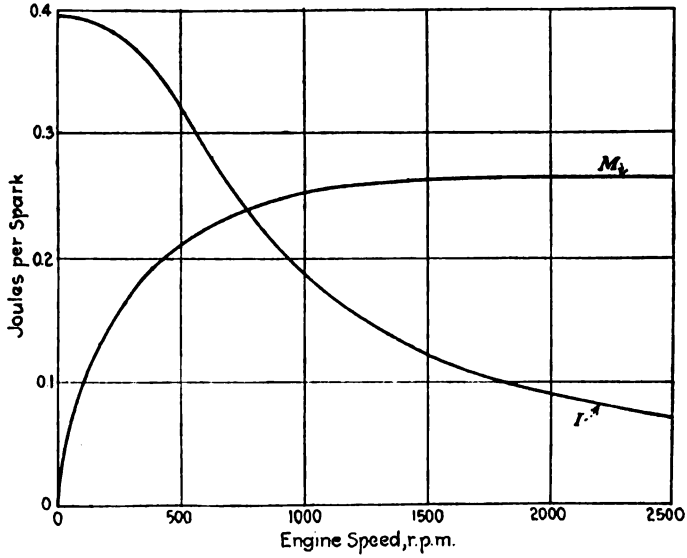

FIG. 7—CURVES SHOWING HOW THE ENERGY PER SPARK FROM AN INDUCTION COIL DECREASES WITH AN INCREASE IN THE ENGINE SPEED AND THE ENERGY IN A SPARK SUPPLIED BY A MAGNETO INCREASES

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speeds. This is however highly desirable when trying to start a cold engine with a low battery. On the other hand, it is difficult to make the magneto spark strong enough at low engine speeds.

There are various things that can be done to improve either one of these conditions, perhaps especially the coil system. It is claimed by those who favor the coil that a very hot spark at very low speed is advantageous. I think every one will admit that this is true. The magneto men say they get plenty anyway, because magneto-equipped cars run successfully; but, under the very lowest speeds, certainly we would get more from the coil than we would from the magneto. On the other hand, the spark grows weaker as we reach the high speeds when using the coil. The coil-makers claim that they get all that is needed and that at high speed not so much energy is required to ignite the mixture successfully as at low speed. The mixture itself is likely to be much better and the compression is perhaps slightly better. This is certainly borne out to the extent that we do get successful ignition with the battery system at high speed, just as we get successful ignition at low speed with the magneto. The magneto manufacturers, on the other hand, claim that they have the hotter spark at high speed, which they argue is advantageous in that the mixture burns more rapidly and develops more engine-power. The battery-ignition man says that the spark-plug points burn away with the strong current. I shall not attempt to decide between the two. I have used both and have had trouble with both.

The much-debated question of whether a hotter spark gives more power in an engine has interested me and I have experimented to a certain extent in regard to it. Suppose I have a sheet of paper that I want to burn. If I apply a small match to the corner of that paper it will burn. The question is, will it burn any faster if I use one of the old-fashioned big matches? I think it makes no particular difference, provided it burns at all. I admit that it is more likely to ignite from a big match if conditions are bad but, provided it does ignite and does burn, I cannot see that the size of the match is going to influence the speed with which the entire sheet of paper will be consumed, and that is what we are concerned with. I contend that the analogy is a good one. In a cylinder the flame travels with considerable velocity but it is a finite velocity just as there is a finite velocity

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of flame-travel for the sheet of paper. Provided the mixture burns at all, I cannot see that it makes much difference whether we have a large or a small spark. If we have the hot magneto-spark it might ignite the mixture when the coil spark would not ignite it at all; but, provided we do get an explosion, I believe that the speed of propagation will be about the same whether the spark is weak or strong.

I have been talking about the energy per spark; joules per spark means just the same thing. The joules per spark has been used by the Bureau of Standards in the comparison of coils, but I think it is not the best basis of comparison. The important thing is not the joules per spark, but the power. Work is, of course, power multiplied by time. I think it does not make much difference what happens at *c*, shown at the right in Fig. 5, but that it makes very much difference what happens at *b* when the spark first passes. The power is surprisingly great for a very short time. It is in the neighborhood of 50 watts, or about as much as a good-sized incandescent lamp takes; but it remains at this value only for an infinitesimal time such as perhaps 0.000001 sec. It raises the temperature of a small portion of the space to a high value for an exceedingly short interval of time. The power that is applied there is the thing that matters primarily. It is not power entirely either; it is power per cubic inch.

Of course it cannot be denied that, in the case of ordinary bodies, the temperature attained is a function of both the power expended and the time. In the case of a spark, however, the conditions are such that the heated matter can and doubtless does get away quickly from the place where the heat is being developed. In other words, I believe that the spark at the instant of formation is very thin and grows rapidly as the spark continues. A small volume of air between the points quickly becomes very hot and the volume then increases, the temperature remaining nearly constant. As I said before, I have no direct proof of this, except some visual inspection of sparks and the above considerations. If a direct proof could be obtained it would greatly clarify our ideas.

Short and Long Sparks

As a further illustration, let us compare two sparks, one short and the other long. Roughly, the gaps are in the ratio of 2 to 1. All dimensions of the sparks are

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also in the ratio of 2 to 1. I think that is practically what takes place with a longer spark. I am very sure it spreads out more and occupies more space. If we compare the volume of those two sparks, it will be as 1 to 8. If we make a thing twice as great in every dimension, it has eight times the volume. Let us assume that the power is in the ratio of 1 to 8, twice the voltage, four times the current. The power per cubic inch however is 1 to 1. The two sparks will therefore be approximately equally hot and the igniting power will be the same. It is true that the larger spark has a greater surface, but that would not make much difference in the rate of flame propagation, as I see it. It would help a little to spread it and the flame would not have to travel so far, but that is a very small matter which I think we can safely neglect. If this analysis is correct it indicates that the power per cubic inch is the proper criterion to use in determining the igniting power of a spark.

To illustrate further by referring again to the sheet of paper, I light it with a match. It does not matter how long the match is, provided the paper lights; the length of the match has absolutely no effect on the rate at which the flame will travel across the sheet of paper. Just so in the case of electric ignition. The follow-over part would have almost no effect because the mixture is already burning. Certainly, as soon as the mixture begins to burn, the heat liberated is much more than the spark could possibly give. It is conceivable that we might not get ignition at the very beginning, and that the follow-over part might possibly ignite it toward the end of the stroke. In that event the explosion would not be worth very much, because it would occur so late in the cycle of the engine.

I have performed one very simple experiment which indicated that, provided we get ignition at all, the power developed by the engine is independent of the strength of the spark. There are many variables in the usual engine-test. For example, we may make a test during a certain hour, and another test several hours later. Perhaps the barometric pressure is not then the same, or the mixture, or the spark pressure, or the degree of advance. A number of things may affect it. I think I left no chance for argument. I did not test as between magnetos and battery systems, but I tested as between hot sparks and weak sparks.

The test was made upon an engine equipped with bat-

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tery ignition. The power output was measured by an electric dynamometer. A throw-over switch was arranged so that the number of cells used to furnish current to the coil could be changed instantly by throwing a switch. As first tried, the ignition voltage could be changed from 6 to 12, *thus increasing the energy per spark four times.* I got the engine running smoothly so that the balance-arm of the dynamometer did not move. I could throw the switch over one way and then the other; there was no difference; nothing happened. The dynamometer-beam never moved and the speed remained absolutely constant. I tried this with all sorts of combinations of cells. I did find that when the voltage became too low the engine began to miss, and of course I obtained more power on high voltage but, so long as the engine did not miss, I could not detect any difference. I tried making the mixture poorer and found that the engine would sometimes miss with the lower voltage whereas it would not miss with the higher voltage. But if everything was all right, there was absolutely no difference in power. I tried it at several speeds; running light and running loaded. The results were the same. I submit that this is a far better test than making a run with a battery and then making a run with a magneto at different times. There was absolutely no chance for change. The spark-advance was exactly the same and the conditions were absolutely identical. The above-mentioned test may be taken as an argument either for or against the magneto. It is wholly understandable that a magneto might be better than a coil system under certain circumstances. I can understand that if the mixture were very poor and the engine running at high speed, the magneto might fire the charge when the coil would not, admitting that there is more energy in the spark. On the other hand, I can understand that at very low speed the coil might fire the charge when the magneto would not.

The amount of variation in the energy per spark that has been used in practice is rather astonishing. I have made a number of tests, and some results are shown in Fig. 8. Some years ago I had a car equipped with a well known magneto, the curve of which is shown at *a*. The curve of a typical battery system is reproduced at *b*. The output of the magneto seems absurdly low, yet I found no fault with the magneto. It ran all right. The engine could not be started on the magneto and a battery was necessary but, aside from that, the engine ran and

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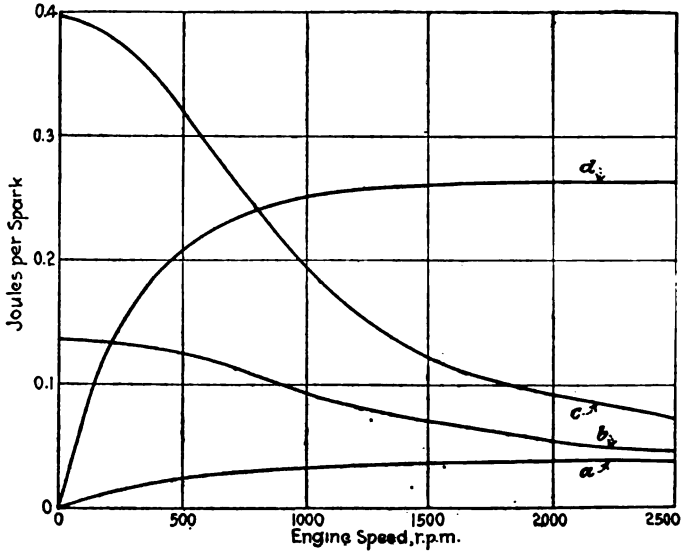

FIG. 8—CURVES SHOWING HOW CHANGES IN THE ENGINE SPEED PRODUCE VARIATIONS IN THE ENERGY PER SPARK SUPPLIED BY MAGNETO AND BATTERY IGNITION SYSTEMS

operated all right with that exceedingly weak spark. The curve *d* shows typical results from a modern high-tension magneto. The spark has sufficient energy to ignite the mixture readily at cranking speeds. The curve *c* is that of a battery-ignition system giving more energy per spark than the coil of curve *b*. All these ignition systems worked fairly well, and there seemed to be enough energy with any of them. This is stated to point out that we can get fairly good ignition through a very wide range of energy per spark. Roughly, measured in thousandths of a joule, these ran from 25 as a minimum to about 325 as a maximum, a range of about 13 to 1, throughout which the operation was fairly satisfactory.

SPARK LAG

Another point worth noting is the lag in an ignition system. There was a large lag in the old-fashioned battery ignition in which a vibrator coil was used because, after the circuit was closed by the primary contact-maker, the current had to grow until enough current was obtained to magnetize the coil and pull the vibrator open. There was a definite time-interval before the vibrator would open and produce a spark, but there was not a

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definite angle. The angle was very small at low speed, and very large at high speed. Also, in the case of the so-called open-circuit system wherein a trigger is tripped and a contact piece is allowed to fly over, make contact and then spring back, we get the same sort of lag because there is a definite time-interval between the tripping of the trigger and the time when the spark is made. The lag is fairly large. It has to be taken care of by automatic advance or by allowing plenty of manual advance. With the ordinary coil of the so-called closed-circuit type the lag is very slight indeed. When the breaker-points start to open the current starts to decrease very fast. It does not come down in a straight line; the decrease is comparatively slow at first and then more rapid. At a certain point the rate of change becomes great enough to give sufficient voltage to make a spark jump across the gap of the spark-plug. The true time of lag is the time from *a* to *d*, at the right, in Fig. 5. The time-interval from *a* to *e* is ordinarily not over 0.0002 sec., so that the time from *a* to *d* would be in the neighborhood of 0.0001 sec. This gives a lag of 1 deg. with an engine operating at 3000 r.p.m. In the case of the magneto we have almost the same thing. The breaker opens in the same way and the current has to decrease in the primary of the armature before the spark passes in the secondary. However, there is this difference. In the magneto at high speed, due to the higher electromotive force, we do not have to drop so far on the curve before we get a sufficient rate of change to make the spark jump. The amount of advance required with the magneto is, therefore, slightly less than that with the battery system. The difference is very small. It amounts only to a fraction of a degree, assuming well designed apparatus.

THE DISCUSSION

FRED WEINBERG:—What is Professor Bailey's opinion of the type of magneto in which the magnetic flux is broken instead of the circuit in the primary? This type of magneto came out some 10 years ago and was made by a company in Massachusetts.

PROF. B. F. BAILEY:—I have heard of that, but I do not know enough about it to have formed an opinion.

MR. WEINBERG:—When you speak about magneto ignition, do you have primarily in mind the type ordinarily known today as the Bosch magneto?

PROFESSOR BAILEY:—Yes, the ordinary Bosch type.

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MR. WEINBERG:—You did not include the so-called Witherbee type of magneto, which in my opinion forms a very strong bridge between magneto and battery ignition. It possesses the strength of battery ignition, together with the strength of magneto ignition, and eliminates the weakness of both.

T. J. LITLE, JR.:—Is it not a fact that as long as the temperature of the spark is well above the kindling point of the mixture to be fired, the ignition will be satisfactory, irrespective of whether the spark is produced from the magneto or the battery system?

PROFESSOR BAILEY:—I think that is true.

MR. LITLE:—That is the real situation. I thought possibly an analogy might exist in kindling a piece of paper, either with a match or an oxy-acetylene flame. The paper does not ignite better in the one case than in the other.

PROFESSOR BAILEY:—That is a very good illustration.

MR. WEINBERG:—There is no doubt that an oxy-acetylene flame would start the paper burning more quickly than a match would. It will take the oxy-acetylene flame considerably less time than the match to start the first part of the paper burning.

PROFFESSOR BAILEY:—If my analysis of the two sparks is correct, one is not any hotter than another. It is simply bigger. Perhaps the analogy that I used between a small match and a large one more nearly fits the case.

MR. WEINBERG:—The length of the match seems to me to be of no consequence, so far as the length of time for burning the paper is concerned. I submit for consideration that the heat of the flame is of consequence as to bringing the fiber of the paper to the temperature at which it will start burning. If it takes some length of time for the fiber to come to the temperature of the flame of the match, then a time-element is involved and the hotter the flame is, the more quickly it will start the paper burning. An analogy is to take that same piece of paper and put it in sodium silicate, commonly known as water glass. I did this and could not light it with a match, but I could light that same piece of paper with an oxy-acetylene flame and it would burn.

PROFESSOR BAILEY:—I think that is a perfectly proper comparison. In other words, I think a hotter magneto spark might ignite a mixture that a weaker spark would not.

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MR. WEINBERG:—Ten years ago I owned a runabout that had the old-time spark which was generated by a dry battery. Sometimes, when I had difficulty in starting, all that was actually necessary was to take my old battery cells out and put new ones in. When I took the spark-plug out and tried the spark, the spark was all right with the old cells. I never could make out why it was that it would not start with the old cells and would start with the new battery.

PROFESSOR BAILEY:—There is no question about that. When I first got a car with a magneto on it, I did not know what to do in case of such trouble. When the battery ignition stopped, after strengthening the battery it would be all right.

MR. LITLE:—A keg of gunpowder as compared to a cylinder in a gas engine would be the better analogy, rather than a piece of paper. The keg of gunpowder can be set off with a match as quickly as with the oxy-acetylene flame.

MR. WEINBERG:—I cannot agree, because gunpowder and dynamite are very unstable compounds and gas mixtures are rather stable. I prefer to take an intermediate step such as in the case of Thermit, which is a compound of aluminum powder and iron oxide. A quantity of Thermit cannot be started burning with a match. That is known. If a strip of magnesium is used as an intermediate agent, and ignited, the Thermit will start to burn from that. This is a point that is well worth investigation. Why does not the Thermit start burning with the match, when it will start with the piece of magnesium which has previously been ignited by that match? In other words, some intermediate agent is used for the purpose of bringing the ignition temperature up to that of the Thermit; the match is not hot enough to set the Thermit aglow. After the Thermit is once started burning it continues very rapidly; but that is after the magnesium has been used. That is in favor of my contention that the original ignition temperature is the prime factor of importance; that is, to bring the gas mixture to the temperature of the igniting medium. This Thermit analogy is submitted to illuminate that particular point.

PROFESSOR BAILEY:—We all recognize that it requires a certain amount of heat to start combustion, and the weak spark will not ignite a certain mixture when a hot spark will. I had one car which frequently would not

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start in the winter because the spark was too weak; when the engine was cranked by hand, thus relieving the battery of the starting current, it would start at once.

A MEMBER:—Suppose a spark in a cylinder 4 in. square and that the spark was 3 in. in diameter. That would ignite the mixture much more rapidly, no doubt. The final burning of the mixture would be much quicker than with a very small spark, but it would not be a desirable thing in ignition because it would approach detonation; in fact, it would be detonation. In other words, the spark would blast its way through the mixture that filled the entire cylinder. It would undoubtedly burn more rapidly, but it would not produce a gas; it would produce an explosion.

PROFESSOR BAILEY:—There is no doubt about that. If I light the sheet of paper on two corners, it will burn faster than if I light it on one corner only. Every one admits that more power is obtained from two sparks than from one. With four sparks I suppose it would be better.

C. F. JEFFRIES:—I think it will be found that the matter of gas turbulence is of more importance than the location of the spark-plug and the number of sparks per cylinder.

PROFESSOR BAILEY:—There is no doubt that is a big factor.

O. E. BARTHEL:—What is your opinion as to the desirability of having more sparks than one in igniting gas in a cylinder? I tried at one time to explain to a court the operation of a vibrating spark-plug, in relation to synchronism and the lag of the spark. We tried to use oscillograph photographs, but found them practically useless as we could not depend upon the operation. It was practically impossible to reproduce a photograph with the same coil and under the same conditions. We gave it up. Finally, we constructed an apparatus by mounting a paper disc and arranging it so that the spark would perforate very fine holes in the disc. This gave a correct curve of the lag of the spark at each setting. By taking the disc off the machine and holding it to the light, an exact view of every perforation was obtained. That was the way we explained to the court the operation of the spark coil, the lag of the spark and the synchronism.

PROFESSOR BAILEY:—There is no doubt either in theory or practice that more power is obtained with two spark-plugs than with one, especially in a very large cylinder. The size of the cylinder has much to do with it. A piece

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of paper lighted on two corners would not take so long to burn as if lit only on one corner. There would be two flames burning in two directions.

A MEMBER:—Might there not be some dead pockets?

PROFESSOR BAILEY:—I assume that neither spark-plug would be in dead gas. Assuming that both spark-plugs fire, it is borne out by tests that some increased power is obtained at high speeds. I have used the same device that Mr. Barthel mentioned for measuring lag. It worked very well indeed, and the effect was easy to see. I do not understand why he should have had so much trouble with the oscillograph.

MR. BARTHEL:—I went to the best engineers, trying to get a device that we could use in a demonstration to the court. They set up scientific apparatus but we found it was not practical. Some old-time coil-manufacturers finally set up the apparatus mentioned for me. It was better than anything I had used previously.

PROFESSOR BAILEY: — The oscillograph shows many things that this simple device would not, but for the one particular purpose stated the latter is very effective. I have used it to measure the lag of a single-spark system.

A MEMBER:—What effect has the width of the gap on the ignition?

PROFESSOR BAILEY:—It depends upon the condition of the electromotive force of the coil and other things. In general, if a coil gives a high enough electromotive force, a somewhat wider gap will probably give more energy. Whether that energy is more effective or not, I do not know. I have stated that I believe that if the gap is widened and the energy distributed over a larger volume, it has not much more power, if any. On the other hand, making the gap too short will interfere more or less with the ignition. I understand that a gap can be so short that there will be no ignition because there is not enough spark.

E. H. VINCENT:—Why do ordinary commercial generators have a greater output cold than warm? Is it caused by resistance?

PROFESSOR BAILEY:—Yes, the resistance of the generator increases very much as it heats up. The rise of temperature is in the neighborhood of perhaps 40 deg. cent. (104 deg. fahr.). The generator becomes hotter and the resistance of copper wire changes 0.4 per cent to the degree. That means a change of about 16 per cent, which is enough to affect the output very ma-

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terially. It cuts down the shunt current about 14 per cent and at the same time increases the armature resistance 16 per cent; it is harder to get the current through and so there is a very decided decrease of it.

MR. BARTHEL:—Is it possible to proportion the winding of the coil so that it will be in exact proportion with the deflection of the spring or vibrator, so that practically synchronous action is obtained? The consensus of opinion seems to be that it is not possible to accomplish that, although one person claimed that he had accomplished it; in other words, by putting additional windings on the core, or the coil, to get an action so that practically the pull will be proportional to the spring deflection.

PROFESSOR BAILEY:—I think it would be extremely difficult, if not impossible, to do that.

MR. BARTHEL:—That seemed to be the consensus of opinion of all the electrical engineers and the coil-manufacturers, and yet it was claimed that this result was accomplished.

PROFESSOR BAILEY:—The pull would run up very rapidly as the iron armature approached the core, and the spring tension would not run up so rapidly.

MR. BARTHEL:—I can understand how an approximation of it would be possible.

PROFESSOR BAILEY:—I do not see that it could be done, except approximately, as you say, because the laws are more or less radically different. With a solenoid it would not be very difficult to do it. There is a considerable range wherein the pull is represented by a straight line and it might be possible to do it by a combination.

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INDIANA SECTION PAPER

HIGH-SPEED ENGINES OF SMALL PISTON DISPLACEMENT

By Louis Chevrolet[1] and C W Van Ranst[2]

In addition to using a smaller quantity of fuel per horsepower-hour, the small high-speed internal-combustion engine has other important features of advantage which are stated. The authors outline specifications intended to secure these advantages.

The high-speed racing engine designed by the authors, which won the 500-mile race on the Indianapolis Speedway in 1920, is illustrated and described in detail, its distinctive features being commented upon.

The automobile should be built to a higher standard for the use of the high-speed engine. The builder should work to a greater degree of precision and, as the working parts of the engine are all light and stressed fairly highly, this necessitates the use of properly heat-treated high-grade materials. Few small cars of this type seem to give satisfaction. The authors look for further developments to counteract this in the near future.

Fuel economy is one important reason for the high-speed engine of small piston displacement. Gasoline was little thought of 25 years ago; the idea that some day we might be without it was a matter of small interest. Today, conditions have changed. The automobile has advanced beyond all expectations and the consumption of gasoline has increased in like proportion. A comparison of the price ratio between gasoline and the automobile of 10 years ago with the ratio of today shows that the automobile has advanced very little, but that gasoline has advanced from three to four times the former price. The low cost of fuel is one reason that has enabled us to carry on large automobile production in this country. What will happen if the cost of this fuel goes beyond the reach of the buying public? The large production of automobiles which we have been enjoying will be cut down materially and conditions will parallel those of Europe. What good will it do to build cars at a low price, if the cost of maintenance is beyond

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the reach of the middle classes? The conservation of fuel is a foundation for large production. Unless the car builder works to that end, or the petroleum producers find a substitute fuel, the automotive industry will suffer.

In addition to using less weight of fuel per horsepower-hour, the small high-speed engine has important features. One is that of light weight, which is a great step toward economy; less power is required to propel the car, less tractive effort is needed and the strain on the tires is not so severe. The flexibility of a high-speed four-cylinder engine approximates that of the "multi-cylinder" engine. The buying public is more familiar with the general construction of the four-cylinder engine than with that of the other types. The cost of repairs also is an important item; the fewer the number of parts that require overhaul, the better the owner should be pleased.

Engine Specifications

Now that the reasons for such an engine and its importance have been stated, we will outline some specifications. The engine should be of the four-cylinder type. As has been said, a high-speed engine should have as few moving parts as is possible; the having of fewer moving parts tends to make it more reliable. It also makes a short engine, which allows more body room and decreases the chances for torsional vibration in the crankshaft. The engine should have a displacement of about 165 cu. in. for a car with a wheelbase of approximately 118 in., a bore of say 3¼ in. and a stroke of 5 in. The valves should be located in the head, as this gives a more ideal combustion-chamber, and should be at least 1⅝ in. in the clear with a lift of at least ⅜ in.

The camshaft should be overhead and run in a bath of oil, but it should be arranged so that no large quantity of oil can get to the valves and cause trouble; otherwise the oil will be drawn in around the inlet-valve stem and have a tendency to foul the cylinders and cause a smoky engine at low throttle-positions. The drive of an overhead camshaft has been more or less a problem. A silent chain is out of the question and the ordinary bevel gear is too noisy, but it seems that the application of a helical bevel gear would solve this problem. The drive from the crankshaft should be taken through a pair of spur gears, to prevent the tendency of crowding because of any lateral motion of the crankshaft. From the spur gear, the drive should be through bevel gears and a vertical

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shaft to the camshaft, a suitable coupling being devised between the cylinder and the head to enable the head to be removed, the carbon deposit cleaned out and the valves ground, without disturbing the timing of the engine. We recommend an overhead camshaft because we believe that lifter-rods and rocker-arms are not practical for high-speed work. The inertia forces of the rocker-arms and lifter-rods run too high to be overcome by any reasonable amount of spring-pressure; it is difficult also to lubricate them properly. In addition, it is almost impossible to maintain proper adjustment, the engine becomes noisy and must be tampered with continually.

The crankshaft is of course a fundamentally important part of this engine. It should be counterbalanced. The crankpins and main bearings ought to be not less than 2⅛ in. in diameter, and there should be at least three main bearings. It is well to drill the crankpins hollow, reducing their weight and at the same time keeping the material at a point where it will do the most work.

The piston, wristpin and connecting-rod must be very light. The length of the connecting-rod should not be over twice the stroke. In the case of the engine described this would be 10 in. The reason for making these parts light is to reduce the load on the bearings as much as possible and to eliminate to a great extent the vibration caused by the differential speed of each pair of pistons as they pass the top and the bottom centers. This type of vibration becomes clearly evident at high engine speeds and cannot, of course, be overcome entirely in a four-cylinder engine.

The cylinders should be cast in block and surrounded with plenty of water, especially around the valves. At high speeds the heat becomes very great at these points; lack of water means distortion of the valve seats, which would cause a drop in power if the engine were run at wide-open throttle. When there is no room for a spark-plug in the top center of the combustion-chamber, we recommend the use of two spark-plugs, one in each side of the combustion-chamber; this gives excellent water circulation around the spark-plugs. We have found that, with engines having spark-plugs in each side, by cutting out the spark-plugs on one side there was a considerable drop in horsepower. Of course, this is more noticeable in engines of relatively large bore than with those having

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a small bore; but it has considerable effect on both, especially with the fuel mixtures we have to burn at present.

The lubrication of the engine should be a pressure-feed in all cases, and oil should be pumped through the engine in as large a quantity as possible. Provision should be made also for carrying a large quantity of oil in the engine; this will give the oil a chance to cool off before being pumped through the engine again. A compartment should be provided in the bottom of the crank-case where the oil will not be agitated, so that the carbon deposits and dirt can settle out. Clean oil adds materially to the life of the engine. We believe that before long engines will be fitted with small centrifugal oil-cleaners that can be removed, cleaned out and replaced without much trouble.

Carburetion on an engine of this type is another problem. To obtain efficiency at high speed the manifold must be large; it should be 1¾ to 1⅞ in. for an engine of the size which we are discussing. A manifold of this size will probably give trouble by loading-up at low engine speeds, and this would interfere with securing the good performance that people look for in an automobile. However, this trouble might be overcome by the use of a double manifold and carbureter, one large and one small, the latter to be used in taking care of speeds up to 25 m.p.h. and the former coming into play from there on. As most of the running of a car is done between 15 and 25 m.p.h. the small carbureter could be run practically wide-open all the time. This undoubtedly would give high economy and, owing to the high velocity of the gases, there would not be a tendency to load-up.

The inlet-manifold should be carefully worked out to assure even distribution of the gases. With a large manifold and a large volume of gas at a high velocity there is a tendency for the gas to bank-up toward the two end cylinders. If this occurs, the two middle cylinders starve and immediately the exhaust-valves of cylinders Nos. 2 and 3 become overheated and burn.

A high-speed engine should be equipped with a four-speed transmission driving direct on the third and geared-up on the fourth speed. On smooth level roads the fourth speed could be used, giving good touring speeds at moderate engine speeds and lengthening the life of the engine. The automobile should be built to a higher standard for the use of the high-speed engine.

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To be successful the manufacturer should work to a greater degree of precision and, as the working parts of the engine are all light and stressed fairly highly, this necessitates the use of high-grade materials properly heat-treated. Several attempts have been made in this country to produce high-speed engines, but for some reason they have not been very successful. However, there are a few small cars of this type that seem to give very good satisfaction, and we look for more developments along this line in the near future.

The Engine Described

Fig. 1 shows the high-speed racing engine designed by us, which won the 500-mile race on the Indianapolis Speedway in 1920. It is necessary in this type of high-

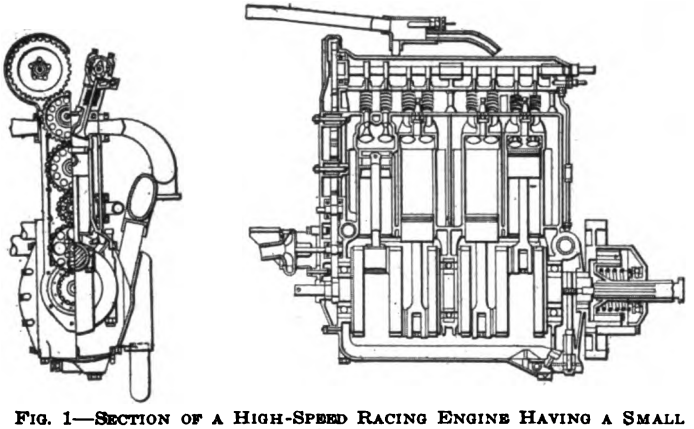

Fig. 1—Section of a High-Speed Racing Engine Having a Small Piston Displacement

speed engine to cut down the friction as much as possible. We attempted to do this in several ways. One is that the water-pump and the ignition system, which consists of a generator and a distributor and forms a unit with the water-pump, are placed in front of the engine and driven by what can be called the idler gears. The last named form part of the set of spur gears which drive the camshafts. Thus we eliminated several gears which usually run off to one side or the other to drive the water-pump and the ignition system. This makes a very clean, narrow and accessible engine.

This engine has two overhead camshafts in separate housings. The valve-actuating mechanism consists of

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a finger having a curved surface forming the section of a roller upon which the cam rides. This finger is to take the side-thrust. Between it and the valve-stem proper there is a straight piece of steel that might be called a tappet. This is the only means of adjustment and is ground to give the proper clearance. This makes a very light valve mechanism and needs very infrequent adjustment.

As to the cooling of the pistons, it is not practical to use the method of heat dissipation through the wall of the piston to the cylinder wall and thence to the water in the jacket, because the wall area necessary in this case to conduct the heat from the pistons is so great as to make the pistons too heavy to travel at the required rate of speed. We have found that it is possible to air-cool these pistons, obviating the large wall area mentioned. This accounts for the unusually large breathers on the side of the engine, one in front and the other in the rear. The front one has a funnel-shaped top covered with a 16-mesh screen which prevents large particles from getting into the crankcase. The air goes in through this front breather-tube, through the crankcase and out through the rear breather, which has an inverted tube facing downward in a compartment separated from the crankcase proper, with a port entering the chamber at the top and also one at the bottom. The breather-tube in this chamber is sealed at the top and has a series of staggered holes down its side. It was designed to take as much air as possible from the crankcase and condense the oil vapor at the same time. The theory is that the air, due to the rotation of the crankshaft, passes in at the upper port and down and around the breather-tube. The oil vapor, settling on the wall surfaces, runs down and out through the lower port and back into the crankcase, while the air escapes through the holes in the wall of the tube and so on to the outside of the car. Of course, there is always more or less oil mixed with the air, and this is lost.

Two separate oiling systems are used on this engine; one mechanical and the other manual. The manual system is for emergencies; it is never used unless something gets out of order in the mechanical system. Both systems are what is known as the dry-sump type. The oil is carried in an 8-gal. tank on the car. There is a two-stage gear-pump which circulates the oil. The lower and smaller pump takes oil from the tank and pumps it

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through the engine; the upper and larger pump takes oil from the engine and pumps it back to the tank. There is a pipe running from the pressure-pump up the back of the engine and connecting with a pipe cast integrally with the cylinder block. Along the edge of the cylinder there are four plugs, which cover a small compartment from which jets project and deliver oil to rings mounted upon the crankshaft.

At the same point where the pipe enters the rear of the cylinder block there is a small pipe which conveys oil up to the camshaft. This pipe enters the rear end of one camshaft housing and is delivered by another pipe across to the other. The two rear camshaft-bearings each have a groove completely around their circumference and, by this groove and through a hole drilled in the camshaft, the oil is forced along the inside of the camshaft, which is drilled hollow. At the heel of each cam there is a 1/16-in. drilled hole, which supplies oil to each cam mechanism. The oil which escapes from the camshaft, after doing its work, is conveyed along the bottom of the housing to the front of the engine where there is a channel beneath the ball bearing which allows it to run out and down over the timing-gears. The oil that does not escape through the small holes in the heel of each cam passes out through the front of each camshaft and also down and over the timing-gears. After the oil goes down through the timing-gear case it runs into the crankcase and along the bottom to a cone-shaped strainer located in the bottom of the crankcase. Through this strainer it is delivered to a compartment which forms a reservoir to allow dirt and carbon to settle out before being taken up by the scavenger pump. The rib along the bottom of the crankcase is not put there for strength, but to form a baffle-plate to prevent the oil from surging about in the crankcase and also to convey it to the scavenger pump.

On the opposite side of the cylinder from the pressure oiling system there is another pipe cast integrally with the cylinder and having two jets, one at either end and opposite the center cheeks of the crankshaft. The oil is taken from the tank by the hand pump at the outward stroke, delivered to these two jets at the inward stroke and projected against the center crankshaft cheeks. The hole drilled in the cheek picks up a quantity of oil every time it comes opposite the jet. This same pump delivers oil to the camshafts by way of the pipe leading from

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the back end of the camshaft housing to the pressure gage on the instrument board. The oil is pumped out of the crankcase and back to the reservoir tank by another hand pump.

The spark-plugs in this engine were made especially for the job. We used one spark-plug per cylinder, located in the center between the four valves, an ideal position. This necessitated an extra-long threaded portion, to get down into the combustion-chamber and still permit water to circulate around the valves. If we had tried to use the standard type of spark-plug, the opening needed would have been so large as to take all the water space.

The adoption of two dial thermometers was an important matter as they give accurate account of what goes on in the engine. One of these which is for water is located in the outlet water manifold. The other is for oil and is located in the lowest part of the crankcase. The oil thermometer is very valuable to the mechanician; the moment a part becomes overheated, from either lack of oil or insufficient clearance, the temperature of the oil rises and is indicated upon the dial of the thermometer. In such case the driver should drive immediately to the pits and inspect the engine for the trouble. On certain occasions when connecting-rods become heated rapidly and the mechanician was either inattentive or had not sufficient time to notify the driver, the connecting-rods have left the engine and been lost to view.

At the left of Fig. 2 the cylinder block and lower half of the crankcase without the side-plates are shown. The valves are in place and also the studs which carry the camshafts and their housing. This cylinder construction should be of interest as it is more or less of a departure from regular practice, inasmuch as the crankshaft is supported by the cylinder itself rather than the cylinder being supported by the crankcase. The crankcase in this case acts merely as an oil retainer. This has proved to be a very light, rigid and satisfactory type of construction. Both sides and the rear of the cylinder block are covered with a No. 16 gage aluminum plate, fastened on with No. 10-24 fillister-head cap-screws. The openings which these aluminum plates cover form very large core-prints, which has a tendency toward securing accurate castings. Castings which we have sectioned have shown that the walls, which run from 1/8 to 5/32

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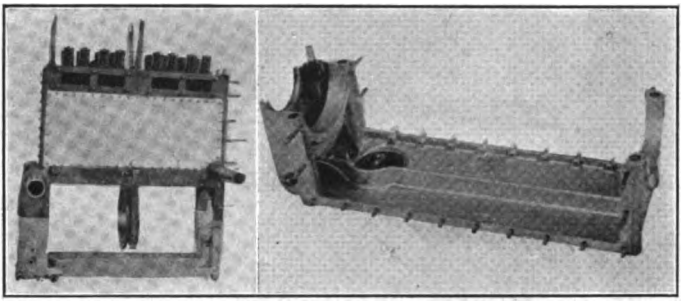

FIG. 2—THE CYLINDER BLOCK AND THE LOWER HALF OF THE CRANKCASE WITHOUT THE SIDE-PLATES AT THE LEFT AND AT THE RIGHT THE LOWER CRANKCASE WHICH CAN BE REMOVED WITHOUT DISTURBING THE CRANKSHAFT

in. in thickness, did not vary. The cylinder block as shown weighs 125 lb. The illustration shows the two steel tubes which support the engine in the frame. By removing the plates on the side of the crankcase, the connecting-rod and piston can be taken out of the engine without disturbing the crankshaft.

The lower crankcase at the right of Fig. 2 can be removed without disturbing the crankshaft, as the center bearing is separate and forms a supporting member. The baffle-plate or rib, already mentioned, can be seen; also the oil-pump and the spiral gear which drives the oil-pump at one-quarter engine speed. This gives the oil-pump a capacity of 1 gal. per min. We have kept the speed of all parts as low as possible to reduce friction losses in the engine.

The view at the left of Fig. 3 shows the connecting-rod and piston. The piston is 2½ in. long, 3⅛ in. in

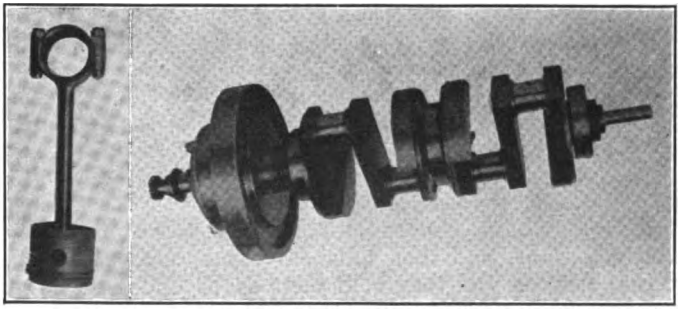

FIG. 3—THE CONNECTING-ROD AND PISTON AT THE LEFT AND THE CRANKSHAFT, FLYWHEEL AND CLUTCH AT THE RIGHT

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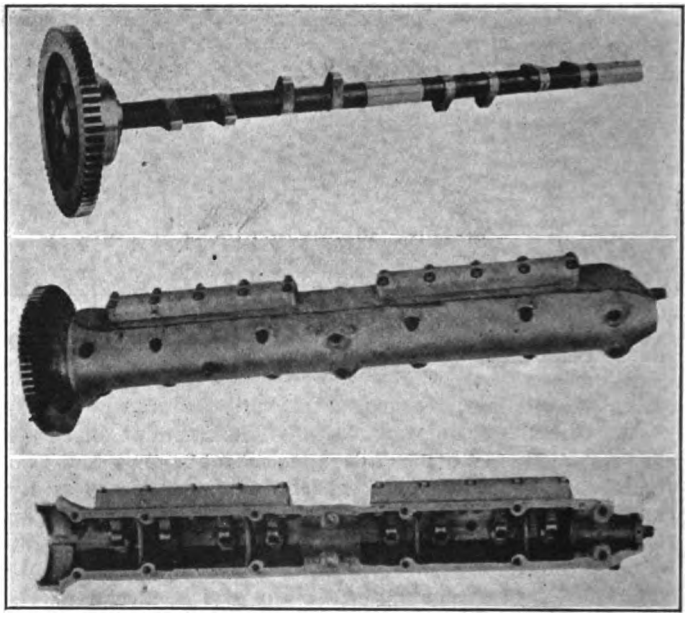

FIG. 4—ONE OF THE CAMSHAFTS AT THE TOP WITH THE COMPLETE CAM HOUSING UNDERNEATH AND AN INTERIOR VIEW OF THE HOUSING WITH THE BRONZE CAPS FORMING CAMSHAFT BEARING AT THE BOTTOM

diameter and has two cast-iron rings, 1/8 in. square. The connecting-rod is made of chromium-vanadium steel containing 0.35 per cent of carbon. The bearing is bronze, babbitt-lined. The connecting-rod has two bolts to hold the bearing cap; the pillar of the rod is drilled hollow and has a wall thickness of 1/16 in. The weight of the piston, with the wristpin and connecting-rod as shown, is 2 lb. 14 oz. The rod is 9 in. between centers. This is short for the amount of stroke, as in ordinary passenger-car practice a stroke such as we have here would call for not less than a 12-in. connecting-rod, but we find that we gain higher mean effective pressures with a short connecting-rod and also decrease the weight of the rod considerably. This connecting-rod has proved very satisfactory and never given trouble. The pistons are of aluminum and rough-machined, heated to about 700 deg. fahr. and then finished. This removes all internal stresses and they hold their shape under the high temperatures they attain in the engine.

The right section of Fig. 3 shows the crankshaft, fly-

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wheel and clutch. The crankshaft is very heavy, weighing 165 lb., and is counterbalanced. It might be advantageous to drill this shaft hollow and lighten it considerably, especially the crankpins. This would reduce also the weight of the counterbalances and thereby decrease the total weight of the shaft without lessening its strength much. The crankshaft is mounted on three ball bearings. It is made in two pieces and assembled in the center. It is locked rigidly by three hardened keys and can be taken apart and reassembled without disturbing its alignment. If we were building another crankshaft of this type we would make the center cheeks more nearly square and drill the center from end-to-end hollow, making it rigid and lighter at the same time. At the front end of the crankshaft the gear which transmits the power required to drive the camshafts is shown.

The upper view in Fig. 4 shows one of the camshafts. There are two plain bearings and one ball bearing in

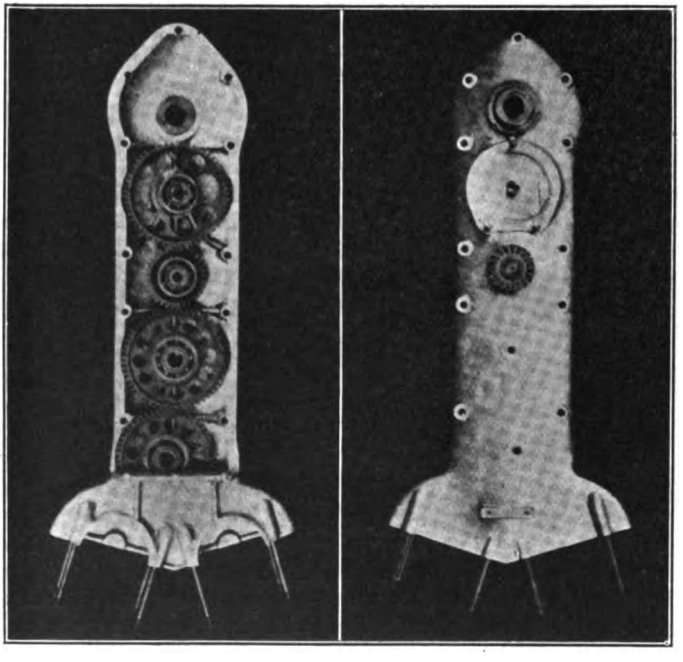

FIG. 5—TWO VIEWS OF THE TIMING-GEAR HOUSING

The View at the Left Shows the One Side of the Housing with the Gears in Place, While the View at the Right Is Looking Toward the Front of the Housing Which Is Fastened to the Forward End of the Engine.

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front which supports the timing-gear. Attention should be called to the heavy rim on the camshaft gear; this is for a flywheel effect. The camshafts run at sufficiently high speeds to store up considerable energy, which assists in opening the valves against the high spring-pressures we use. These are in the neighborhood of 125 lb. The cam has a lift of 7/16 in. The camshaft, drilled hollow as mentioned, has a wall thickness of ⅛ in.

The complete cam housing is illustrated in the middle portion of Fig. 4, while the bottom view shows the interior of this housing with the bronze caps forming the camshaft bearing and the fingers, which have been mentioned before, in place with their housing. By removing small screws the fingers can be removed in units of four, inspected, repaired if necessary and replaced in a very short time. The channel, which has been mentioned, is shown underneath the ball bearing, where the oil is allowed to run out at the front of the housing. The fingers do not have rollers but simply curved surfaces.

Fig. 5 presents two views of the timing-gear housing. That at the right is looking at the front of the housing, which is fastened to the forward end of the engine. The bottom hole is where the crankshaft projects through. The machined surface above it is for the water-pump and generator bracket. The shaft in the middle drives the water-pump. Above it is a toothed flange which is part of the generator coupling. The coupling at the generator has one tooth less. A rubber member which fits in between the flanges enables a micrometer adjustment to be made and the rubber center member provides a flexible joint that absorbs much of the shock present in timing-gears. The other side of the timing-gear housing is shown at the left of this illustration with the timing-gears in place. These gears are made of chromium-vanadium 0.50-per cent carbon-steel, heat-treated. The teeth are 12-pitch. The webs are drilled hollow for lightness and mounted on a single-row ball bearing. The ball bearings are held in the gear by simply turning over the edge of the gear against the chamfer on the outer race of the ball bearing. The lower gear drives the water-pump. The one directly above and meshing with this gear drives the generator. This gear is really smaller than it should be, as the engine was originally designed to take a magneto that had to run at crankshaft speed, which is much faster than is really necessary to run a low-voltage generator.

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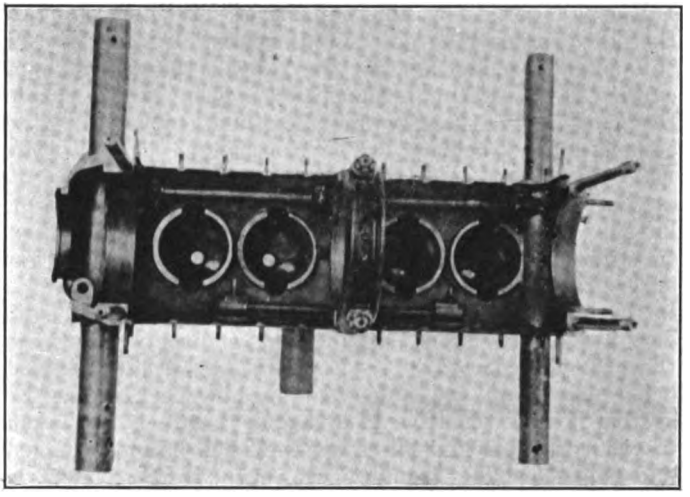

FIG. 6—LOOKING INTO THE CYLINDERS FROM THE BOTTOM

It was determined after test to use the battery system of ignition in place of a magneto on account of the high engine speed, which is from 3400 to 3600 r.p.m.

Fig. 6 is the view seen when looking into the cylinders from the bottom. It shows clearly the oil-pipes already spoken of, the valves in place in the head of the cylinder and also the steel supporting tubes.

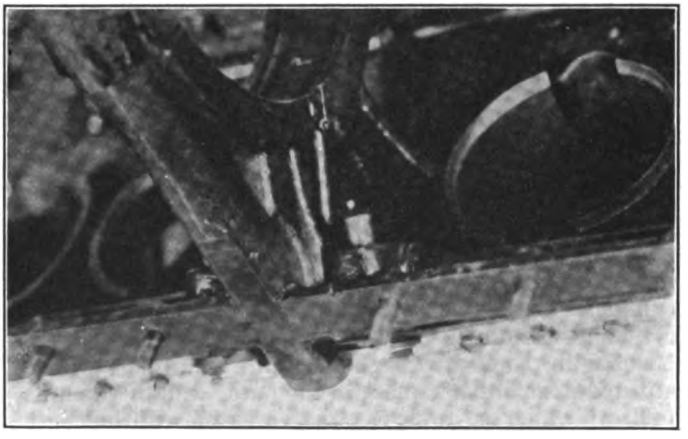

FIG. 7—THE OIL-JET WHICH SUPPLIES LUBRICANT TO THE OIL-RING ON THE CRANKSHAFT

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Fig. 7 is a close-up view of the oil-jet which supplies the oil to the oil-ring on the crankshaft. The oil leaving this jet is directed against the side of the oil-ring and carried by centrifugal force into a deep groove inside the ring and a hole connecting this groove with the connecting-rod bearing. The centrifugal force in this ring of oil exerts a pressure of about 40 lb. per sq. in. at the connecting-rod bearing. This system of oiling has its advantages and disadvantages, a very good feature being that the oil can be carried under high pressures to the connecting-rod without excessive pressures in the pipe lines which go to and from the engine. This does away with the danger of leakage through joints, as the pressure carried in the pipe lines need never exceed 5 lb. per sq. in. One disadvantage, however, is that the system is very sensitive to dirt and, if care is not taken to clean the jets and oil-rings, they will become clogged and cause bearing trouble. However, if the system is carefully watched, satisfactory results will be obtained.

Fig. 8 at the left shows the generator, distributor and water-pump unit, which is fastened into the forward end of the engine. This might have been executed in a more compact manner had it not been a replacement for magneto equipment. For the high speed at which this engine ran, battery ignition proved to be very successful. At no time during our season of racing have we had ignition trouble.

A view of the complete engine, with the magneto equipment as when the engine was first built, is presented in the right portion of Fig. 8. Attention is called to some experience we had with the distribution of gases. The manifold shown has an inside diameter of 2 in.; owing to its shape, we found that at high engine speeds the gases would travel toward the front and back of the engine; before cylinders Nos. 2 and 3 could take in a charge, it was necessary for the gas to bank-up in the end of the manifold and form its own passage to cylinders Nos. 2 and 3. This, of course, had a tendency to starve the two middle cylinders. A mixture suitable for the end cylinders would cause overheating of the two middle cylinders, resulting in the overheating of the valves. Not having time to experiment with manifolds, we substituted a small baffle-plate in the outer wall of the manifold, which served to deflect the gases toward the center. By a small amount of experimenting, which was merely cutting off the end of this baffle-plate and watching the

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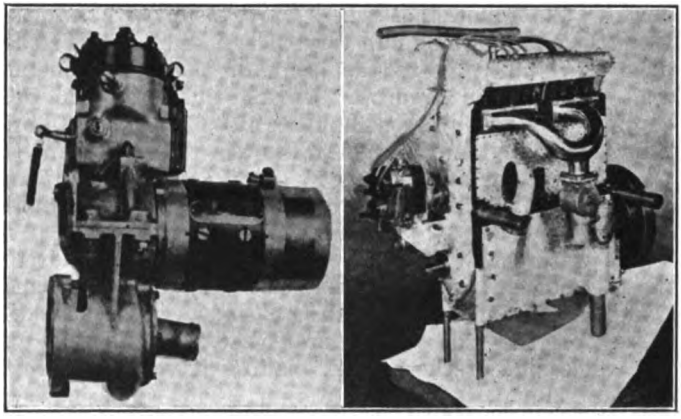

FIG. 8—THE GENERATOR, DISTRIBUTOR AND WATER-PUMP UNIT WHICH IS FASTENED INTO THE FORWARD END OF THE ENGINE AT THE LEFT AND AT THE RIGHT A VIEW OF THE COMPLETE ENGINE AS IT WAS FIRST BUILT WITH THE MAGNETO EQUIPMENT

exhaust, we were able to determine the proper setting. Unfortunately, this held good only at one certain speed; dropping below or going above that speed tended to reverse conditions and again cause trouble; but, as in our case the engine ran practically at a constant speed, we were able to use the manifold with fairly good results. We also tried the use of two carbureters with separate manifolds, but this was not at all satisfactory. The velocity of the gases was so great that when the valves closed there was a plus pressure against the back of the valves which resulted in a blow-back through the carbureter. To correct this we tried a by-pass from one manifold to another to allow the plus pressure to be conveyed to the other manifold, but this did not prove successful.

The valves in this engine have a diameter of 1 7/16 in. in the clear, and a lift of 7/16 in. The area of opening for one valve is 1.70 sq. in.; the total valve area is 6.81 sq. in. The engine, on the dynamometer, delivered 86 hp. at 3200 r.p.m. This is not as high as has been reported from tests of eight-cylinder engines of the same piston displacement. On a test under a wide-open throttle this engine, running at 3200 r.p.m., delivered an average of 78 hp. for 1 hr. The result might have been better had the air in the test-room not been contaminated with exhaust gases, causing a considerable drop in the horse-

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power. We found that when starting up with a clear room the engine would pull very well; as the room became filled with burnt gases the beam of the dynamometer scale would begin to drop. During this 1-hr. run the engine had a gasoline consumption of 0.625 lb. per hp-hr. This same engine ran 500 miles on the Indianapolis speedway at an average speed of 88.7 m.p.h., with an average of 10 miles per gal. of gasoline for the whole race.

The water manifold, with a small pipe which leads to the thermometer, and the breather pipes, front and rear, is shown. It can also be seen how the covers come completely off the side of the crankcase. This opens up the whole side of the engine, making it very accessible besides being very light in weight. The whole engine, with exhaust-manifold complete, weighs 410 lb.; a large part of this weight is, of course, in the crankshaft, which weighs 165 lb.

THE DISCUSSION

A MEMBER:—At what engine speed was maximum horsepower obtained?

C. W. VAN RANST:—At maximum horsepower on the block the engine speed was 3200 r.p.m. On the track we continued up to 3500 and 3600 r.p.m.

MAX H. THOMS:—What is the axle ratio?

MR. VAN RANST:—It is 3 to 1.

MR. THOMS:—What sizes of tire were used?

MR. VAN RANST:—Three cars, the winner among them, used 32 x 4-in. front and 32 x 4½-in. rear tires. The others used 32 x 4½-in. front and 33 x 5-in. rear tires.

MR. THOMS: — What is the material in the flywheel? What is its diameter?

MR. VAN RANST:—The material is plain carbon-steel; the flywheel diameter is 13 in.

A MEMBER:—Please describe the breather system, from the radiator to the crankcase.

MR. VAN RANST:—The air comes through the radiator and there is enough draft to force it through the crankcase. The ideal condition would be to take it from outside, but the air comes through the radiator so fast that it does not heat up to a high degree and so it makes no difference.

A MEMBER:—Do you have trouble with accumulations of dirt in the oil?

MR. VAN RANST:—The greatest trouble in taking air

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into the crankcase is with dirt; it is serious and a thing we would like to get away from. We have to give the crankcase air or it will become too hot. There are means, I suppose, whereby we could get a less amount of dirt. I think it important to give all the air possible. That is one reason I mentioned that the crankcase should be fitted with a compartment where the dirt and carbon can filter out of the oil and not be carried through the engine.

GEORGE A. WEIDELY:—You obtained 10 miles per gal. of gasoline; how many miles did you obtain per gallon of oil?

MR. VAN RANST:—We prefer not to state that figure because this type of engine is not economical with oil. Due to the arrangement of the camshaft and because the valve mechanism is open, much oil is lost. The racing-car engine, unfortunately, seems to slobber a lot of oil, anyway; especially in this type, where the breather is large and the cam housing is overhead. The oil consumption was very high.

CHESTER S. RICKER:—What kind of oil was used?

MR. VAN RANST:—Straight castor oil. We tried mineral oil but found that the carbon deposit was too great and caused us to burn out three connecting-rods. After we used castor oil we never burned out a rod. The other oil would become foul and the jets would clog; immediately a rod would burn. With castor oil there was very little carbon and the oil had greater body. The temperature of the oil runs anywhere from 220 to 250 deg. fahr.

A MEMBER:—Do the fingers on the cams take all the thrust of the cams?

MR. VAN RANST:—Yes.

MR. THOMS:—What tappet clearances are there on the exhaust and inlet-valves?

MR. VAN RANST:—The exhaust has 0.030 in. and the inlet 0.025-in. clearance.

A. L. NELSON:—In regard to experiments with fuels and compression-ratios, what was done?

MR. VAN RANST:—We carried on a few experiments. Recently we tried a "dope" which Mr. Kettering prepared to retard the speed of combustion and prevent detonation. We found that in this type of engine it proved to be of no advantage. We experimented with compressions up to 135 lb., varying the percentage of dope to gasoline from 3 to 3½ per cent; but we lost power as compared to

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regular practice. The compression-ratio that we found to be best was 5 to 1, which gave about 105 lb. per sq. in. gage compression.

A MEMBER:—What is the comparison of an engine of the type described with the standard type, as far as quietness is concerned?

MR. VAN RANST:—At ordinary traveling speed there is no reason it should not be as quiet as the average engine of today. I believe it would be more quiet than engines with the rocker-arm and lifter-rod valve actuation used in the cheaper classes of car. Also, at higher speeds I believe it would be more quiet; but there would be less tendency for the valves to flutter, due to the elimination of rocker-arms and lifter-rods, although at higher speeds there is a considerable hum anyway. I believe the noise would not be detrimental. I know of no engine that I would call quiet when running at high speed.

DANIEL C. TEETOR:—Is there anything special in regard to the design of the piston-rings?

MR. VAN RANST:—No; they are of cast iron, cast separately and machined to be ⅛ in. wide and ⅛ in. deep; two rings are used, with just an ordinary 60-deg. slot.

A MEMBER:—How much clearance is there beneath the rings?

MR. VAN RANST:—The clearance is 0.010 in. overall; that is, 0.005 in. on each side.

A MEMBER:—What material is used for the timing-gears?

MR. VAN RANST:—They are of chromium-vanadium steel containing 0.50 per cent of carbon and heat-treated.

A MEMBER:—How are the timing-gears kept quiet?

MR. VAN RANST:—We do not attempt to keep them quiet; they hum considerably when running. They could not be made quiet, because the webs are drilled, this tending to make them noisy.

A MEMBER:—How could that be corrected in a commercial car?

MR. VAN RANST:—I would recommend the use of helical bevel gears, having them drive a vertical shaft to the overhead camshaft.

ARTHUR HOLMES:—In what manner are the wristpins lubricated?

MR. VAN RANST:—By splash. Two small holes are drilled in the top of the wristpin boss and there are grooves the full length of the bearing inside. The oil coming from the connecting-rods is thrown upward into

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the cylinder and is picked up by these holes. Oil is also picked up from the cylinder wall by the wristpin hole.

LON R. SMITH:—What is the size of the crankshaft?

MR. VAN RANST:—The crankpin is 2⅛ in. in diameter. The main bearings are ball bearings 2¼ in. long and are very large.

A MEMBER:—Do you use shims in the connecting-rods?

MR. VAN RANST:—There are no shims and no grooves. We could not use shims, as this would cause a slot the entire length of the bearing which would allow the oil to pass through, because it is under such high pressure, and would probably cause a smoky engine. We have to keep the bearing as tight as possible, aside from the necessary clearance.

A MEMBER:—What is the pressure of the oil at the connecting-rods?

MR. VAN RANST:—It is calculated to be 40 lb. per sq. in.

A MEMBER:—Did you have any difficulty with the babbitt separating from the bronze bearings?

MR. VAN RANST:—There were only two or three instances that I know of the babbitt becoming loosened from the bronze.

MR. WEIDELY:—Those who have interested themselves in racing or other contests are familiar with the fact that many such events have been won by road ability rather than because of engine output; on the other hand, faults of the present-day motor-car often are found in parts other than the powerplants.

The limiting of displacement in our more important races has supplied an incentive to develop engines having abnormal torque at an abnormal compression and a still more abnormal speed, which has resulted in research along the line of engine improvement to the exclusion and detriment of improvement in other almost equally important parts of the car. It is doubtful whether the results gained in racing events help to improve the commercial article as much as they might and would if rules and conditions were added covering fuel and oil consumption, power losses, tire wear, acceleration, ability and durability of brakes and other things looked for in the modern car.

In view of the fact that probably all present-day cars, racing or otherwise, show a power loss at the wheels of over 20 per cent exclusive of slip, there seems to be food for thought in a direction other than toward the engine.

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It is true that these matters might detract from the sporting side of a contest, but the results from such events would, no doubt, pay in a big way if these matters were considered. I have just learned that the part of the rules covering the bench and dynamometer tests of all cars entered in the Grand Prix Race, in France, has been dropped. This is really a misfortune for the industry as a whole, as otherwise no doubt much useful information could have been gained.

Mr. RICKER:—There was recently a very interesting contest in France in which the fuel-consumption was the criterion rather than the engine displacement. The question of a bench test for the French Grand Prix Race was largely, I understand, a matter of not desiring to put an engine to that test before it had to go into the race. A race is a question of a complete chassis rather than one of the engine alone. On a bench test the engine might break down or a good engine that did not fulfill the exact conditions might be eliminated; yet the engine and the chassis in which it was installed might make an ensemble that would win the race. Some of the suggestions that Mr. Weidely makes might well be considered by automotive engineers and especially by the automobile contest organizations of this country.

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METROPOLITAN SECTION PAPER

THE STATUS OF THE ISOLATED GAS-ELECTRIC GENERATING PLANT

By Charles Froesch[1]

Statistics taken from a report made by the Department of Agriculture regarding the number and size of farms in the United States indicate that approximately 2,580,000 farms are available as a market for the isolated gas-electric lighting plant. The common types of lighting plant are classified in three groups, each of which is subdivided into three classes, and these are illustrated, described and discussed.

The characteristics of the ideal farm lighting-plant are enumerated and discussed as a preface to a somewhat lengthy consideration of the factors that influence the design of the component parts, which are grouped as pertaining to the engine, the generator, the switchboard and the battery. Storage batteries are still considered the weakest part of the isolated plant and they are specially commented upon. The author emphasizes that much still remains to be accomplished as regards the stability of design, reliability and economy of the isolated plant.

Electricity is unquestionably the most satisfactory medium used today for power and light, not only because it is safe, convenient and most flexible, but because it is beautifying and attractive. The low cost of fire insurance made possible by the use of electricity on the farm almost warrants its installation, this being 50 or 60 per cent of the cost of insurance when other lighting methods are employed. Electric light and power for the farm are meeting with constantly increasing popularity and, as only a comparatively small number of farms are electrified at present, the lighting-plant market is growing with surprising rapidity. To understand the magnitude of this field and its requirements, a brief survey of existing conditions is necessary. The following figures taken from a statistical report issued by the Department of Agriculture, while approximate at best, cannot be ignored.

[1]Jun. S. A. E.—Chief engineer, S. W. Merritt Co., New York City.

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There are today 6,400,000 farms in the United States having an average area of 140 acres. However, only 40 per cent of these have more than 100 acres of area. It would not be fair to judge the market for isolated plants by these farms only, because many farmers having less than 100 acres can well afford to buy a lighting plant, while many owners of larger farms cannot or would not. We can say conservatively that one-third of the smaller farms and four-fifths of the larger ones form the future market. This gives a total of 3,328,000 farms. However, we must deduct from this total a number of different plants already installed and farms supplied directly by central power stations. Estimating the total number of isolated electric plants made up to the present at 200,000, and the number of farms supplied with central-station current at 7 per cent of the total, approximately 2,580,000 farms are available as a market for the isolated gas-electric lighting plant. Farmers are most conservative and discriminating and speak and act from experience. It is my firm belief that when the usefulness and necessity of the isolated lighting plant shall have been fully proved, every one of these farms will be electrically lighted.

Adequate central-power-station development and service extension in the rural districts cannot be realized in the near future. The influx of people to the cities and the increase in cost of labor and material will keep the utilities companies busy with city problems for several years to come, leaving the field clear of serious competition for the isolated-electric-plant manufacturers. It is true that here and there some steps have been taken to install high-tension electric lines in the country, but in most cases this experiment has been costly to the ultimate consumer, current being generally furnished on a kilowatt-mile basis plus an additional fee for equipment depreciation. The above analysis does not include the possibilities of the use of lighting plants for schools, halls, stores, camps, yachts and the like, or the vast field offered through export.

A lighting plant is expected to give light whenever it is needed and at as low a cost as possible. When the low-voltage plant first appeared several years ago, it was a rather crude affair consisting of a generator, a switchboard and a set of storage batteries, all mounted on a wooden base which in turn was bolted wherever convenient. It was invariably belt-driven by a gas engine

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bought separately and in most cases too large or too small to handle the generator load efficiently. The voltage regulation, if any, was poor, and the battery entirely too small; but in spite of this the equipment gave fairly good results in the hands of the layman and was decidedly better than kerosene or acetylene lamps. Latterly special engines and generators have been designed and storage batteries greatly improved as to life and relia-

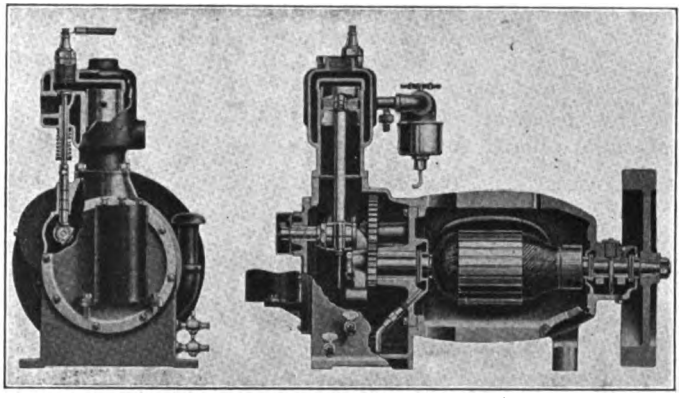

FIG. 1—END AND SIDE SECTIONAL VIEWS OF A 32-VOLT 300-WATT FULL-AUTOMATIC PLANT

bility. The whole system has been specially adapted to the work to be done.

COMMON TYPES OF LIGHTING PLANT

Farm lighting plants can be classified in three groups:

(1) Full-automatic plants which, as their name implies, start and stop automatically when the battery is discharged or recharged respectively.
(2) Semi-automatic plants, which must be started by hand but stop automatically when the battery is fully recharged
(3) Assembled plants, which do not contain any automatic features and are in the majority of cases belt-driven

Each one of these groups is made for 32 or 110-volt service. Some plants have been designed for 60-volt service, but their use is very limited owing to inability to secure motors and electrical appliances that can be run

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in conjunction with them. I understand that they are used exclusively for motion-picture apparatus.

Each one of the main groups of plants can be subdivided into three classes as follows:

(1) Plants furnishing power from the generator alone
(2) Plants furnishing power from the generator and the battery, or the battery alone
(3) Plants furnishing power from the battery and generator combined, or from the battery or the generator alone. The 32-volt semi-automatic plants furnishing power from the generator and the battery, or from the battery alone, are the best known plants today

The specifications issued by the lighting-plant section of the National Gas Engine Association regarding bat-

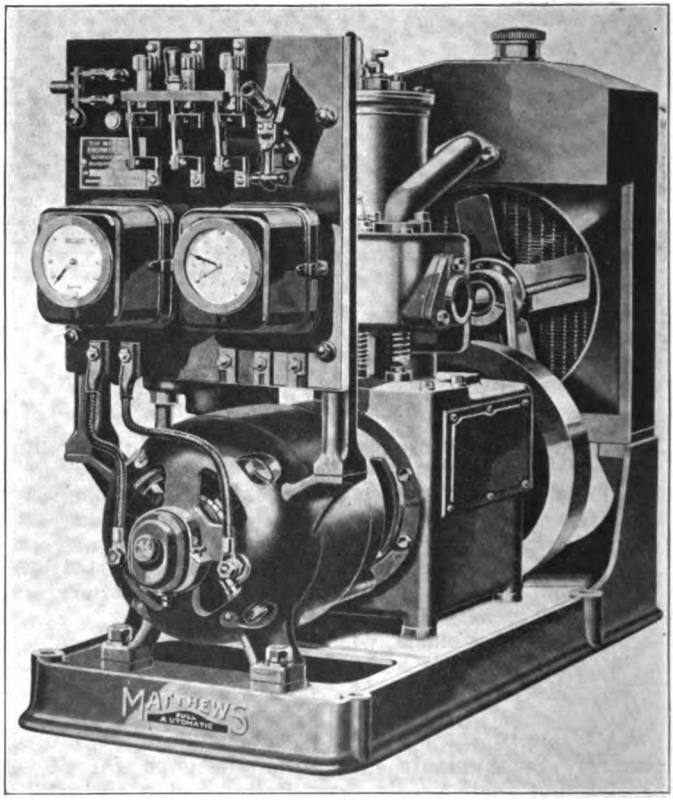

FIG. 2—A 1-KW. FULL-AUTOMATIC PLANT

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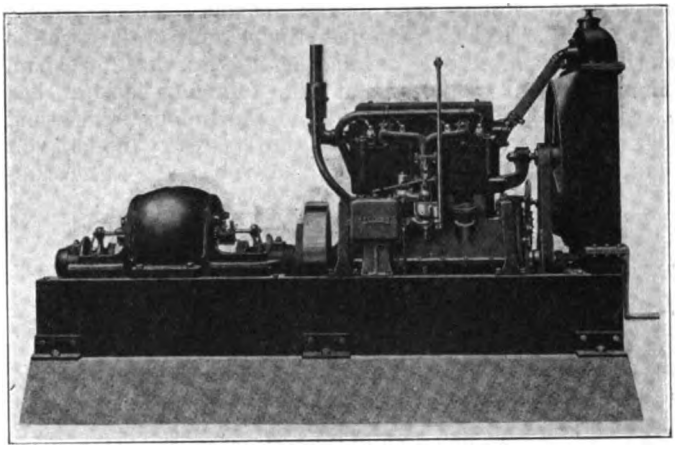

FIG. 3—A 5-KW. 110-VOLT AUTOMATIC PLANT WHICH IS USED IN CONNECTION WITH A 108-AMP-HR. BATTERY

tery equipment and generator rating are interesting and worth noting. The following cell equipment is recommended for these plants:

(1) For 32-volt service, 16 cells of the lead type; or 25 cells of the Edison type
(2) For 60-volt service, 32 cells of the lead type; or 50 cells of the Edison type
(3) For 110-volt service, 56 cells of the lead type; or 92 cells of the Edison type
(4) Generators are to be rated in watts, with a supplementary rating in amperes if desired
(5) For 32-volt service, the generator shall deliver 36 volts at full load. For 60-volt service, the generator shall deliver 72 volts at full load for continuous operation. For 110-volt service, the generator shall deliver 125 volts

The Consolidated Utilities Corporation manufactures a complete line of lighting plants ranging from 300 watts, for the 32-volt type, to 10 kw. for the 110-volt type. Its plants are known to the trade as the Matthews plant. They are made either with full-automatic or semi-automatic control. Fig. 1 shows the 32-volt, 300-watt plant. It has a one-cylinder four-cycle gasoline engine of 2-in. bore and 3-in. stroke, developing 1 hp. at 1200 r.p.m. The generator has a maximum capacity of 450 watts. Two sizes of battery are furnished with this plant, a 55 amp-hr. glass-jar type, or a 70 amp-hr. en-

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closed-type rubber jar. Fig. 2 shows the Matthews 1-kw. plant. It has a single-cylinder four-cycle gasoline engine of 3-in. stroke, developing 3½ hp. at 1250 r.p.m. The generator which is of the four-pole design has a capacity of 1000 watts for continuous operation. The battery capacity is 75 amp-hr. for the 32-volt sets, and 36 amp-hr. for the 110-volt sets. The full-

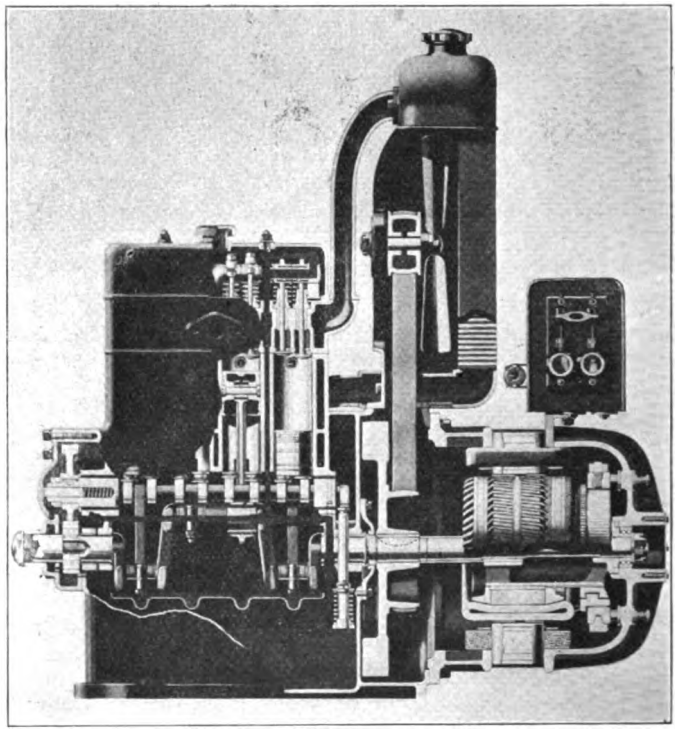

FIG. 4—SECTIONAL VIEW OF A 110-VOLT FULL-AUTOMATIC PLANT WHICH HAS A FULL-PRESSURE OILING SYSTEM AND DOES NOT USE A LIGHTING BATTERY

automatic switchboard is shown. On the left is an ordinary ampere-hour meter and on the right a similar meter controlling the battery automatically. Immediately above the latter meter is the overload circuit-breaker, which disconnects the circuit as soon as the load increases above a safe limit.

Fig. 3 shows one of the largest Matthews plants, made only for 110-volt service and used with a 108-amp-hr.

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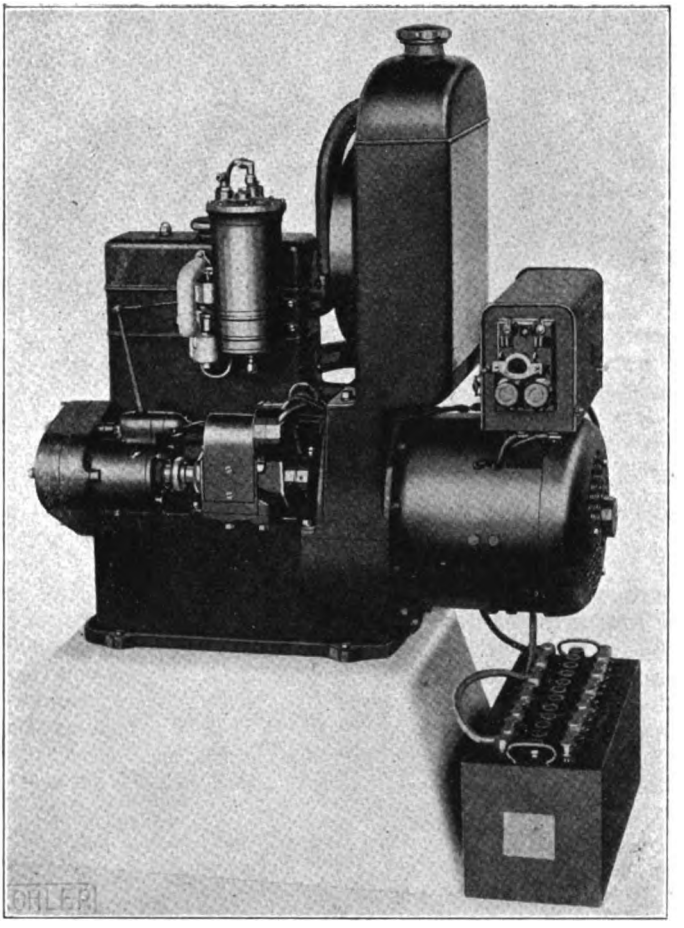

FIG. 5—EXTERIOR ELEVATION OF THE PLANT ILLUSTRATED IN FIG. 4 SHOWING THE 24-VOLT BATTERY THAT IS EMPLOYED FOR STARTING PURPOSES ONLY

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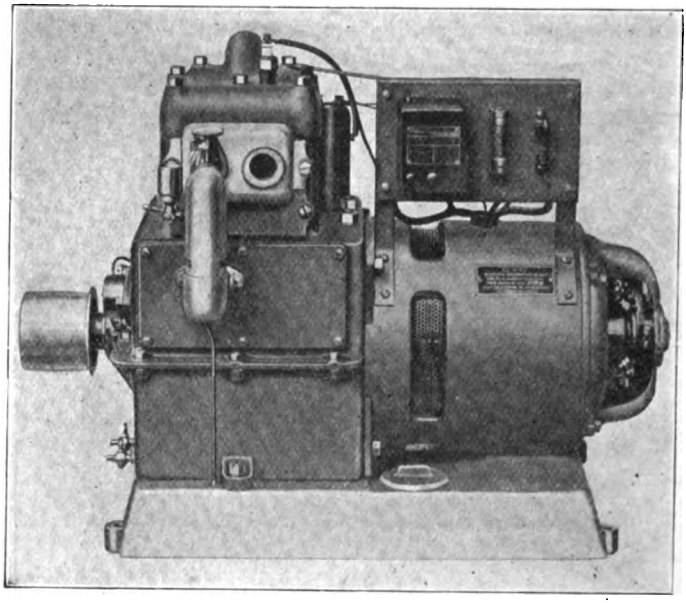

FIG. 6—A 1½-KW. 32-VOLT PLANT EQUIPPED WITH A PULLEY FOR DRIVING ACCESSORIES BY A BELT

battery. This plant is rated a 5 kw. The engine is a four-cylinder four-cycle overhead-valve type, having 3½-in. bore and 5-in. stroke and developing 20 hp. at 900 r.p.m., its rated speed. The generator is 110-volt for starting and lighting, with a separate booster commutator for charging the battery. It is driven by a fabric disc coupling. The switchboard is arranged for full-automatic control and has a starting rheostat, a separate voltmeter and an ammeter.

Fig. 4 shows another full-automatic plant, made by the Kohler Co. It is a 110-volt plant without a lighting battery. The only battery used is a 24-volt set for starting purposes only. Depressing any light switch in the circuit automatically starts the plant; when the light goes out, the plant stops. It has a four-cylinder engine of 2-in. bore and 3-in. stroke, developing 3½ hp. at 1000 r.p.m. The engine follows standard automobile engine practice, having magneto ignition and a float-chamber carbureter with a vacuum feed system. This generator is rated at 1½-kw. and is compound wound. The switchboard provides complete automatic control of

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the plant; the controls are sealed in a box. Fig. 5 shows the complete installation.

The smallest of the Delco plants, which is seemingly one of the most popular, has all of the bearings of the ball or roller type and the generator armature is overhung. This plant is of the 32-volt semi-automatic type and is used in conjunction with a storage battery of 160-amp-hr. capacity. It is rated at ¾ kw. It is an air-cooled plant, air being drawn through slots in the head cover and the cylinder, and expelled by a fan flywheel of the sirocco type. Lubrication is by splash from the gears. The crankshaft is counterbalanced.

The largest size of Delco plant develops 3 kw. and is built for 110-volt service only. Its design and construction are similar to that of the smaller size. The Delco plants are made to run on either gasoline or kerosene. A water system designed by the Delco engineers for use in conjunction with lighting units has a small electric motor operating a single-cylinder water-pump through a train of worm gears, in conjunction with a water tank; it is automatic in its operation, starting

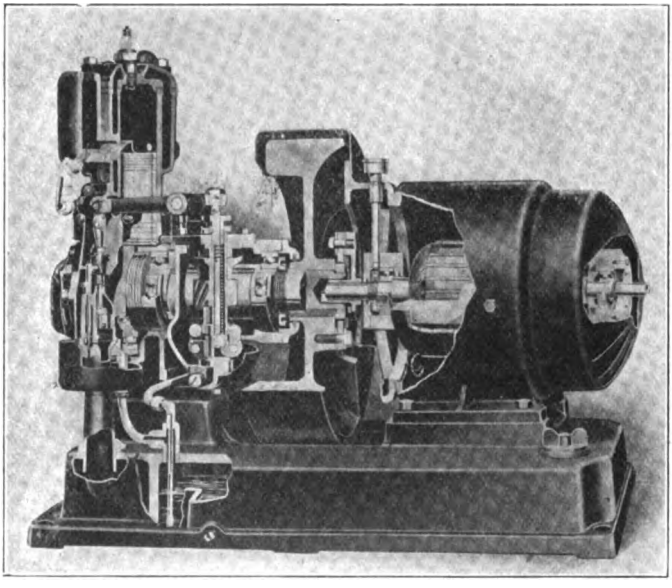

FIG. 7—ELEVATION, PARTLY IN SECTION, OF A SEMI-AUTOMATIC PLANT IN WHICH THE FLYWHEEL IS PLACED BETWEEN THE ENGINE AND THE GENERATOR AND THE FUEL IS STORED IN THE BASE

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when the tank is empty and stopping when fully recharged. It works on the pressure principle.

Fig. 6 shows the C-Y-C plant built by Carlton, Young & Catlin, Inc. It is a 1½-kw. 32-volt plant, comprising a single-cylinder four-cycle gas engine of 3¾-in. bore and 4-in. stroke, developing 5 hp. at 1200 r.p.m. It is equipped with a pulley for directly driving accessories. The generator is of the two-pole design and compound-wound. The switchboard control is of the semi-automatic type. The piston, rings, pin, connecting-rod, valves and springs of the engine are standard Ford parts. This ought to be an advantage when repair parts are needed.

Fig. 7 shows a sectional view of the Lalley plant. It is a 32-volt semi-automatic plant of 1¼-kw. capacity. The engine is of the single-cylinder water-cooled two-cycle type, having 2⅝-in. bore and 2-in. stroke. It is governed mechanically to run at a speed of 1800 r.p.m. and develops 2½ hp. at that speed. Lubrication is provided by mixing a certain amount of oil with the fuel

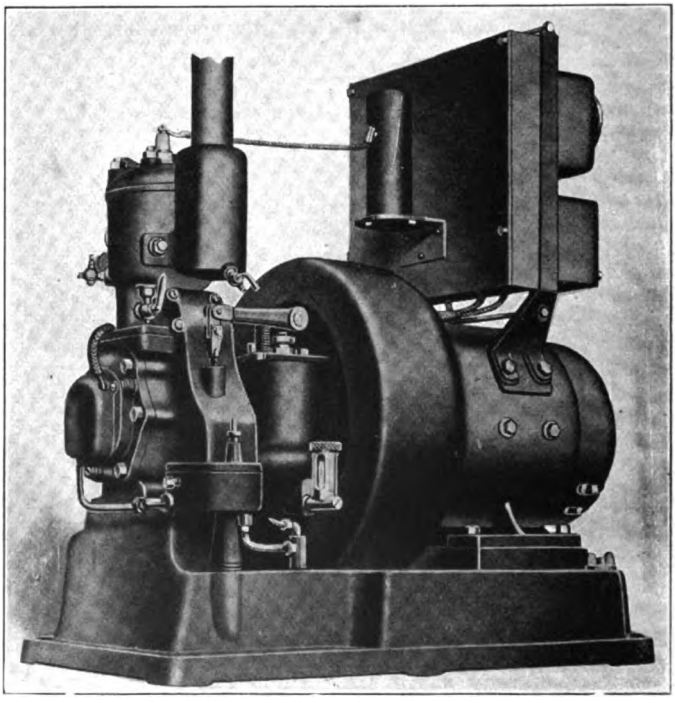

Fig. 8—An Exterior View of the 1¼-Kw. Plant Shown in Fig. 7

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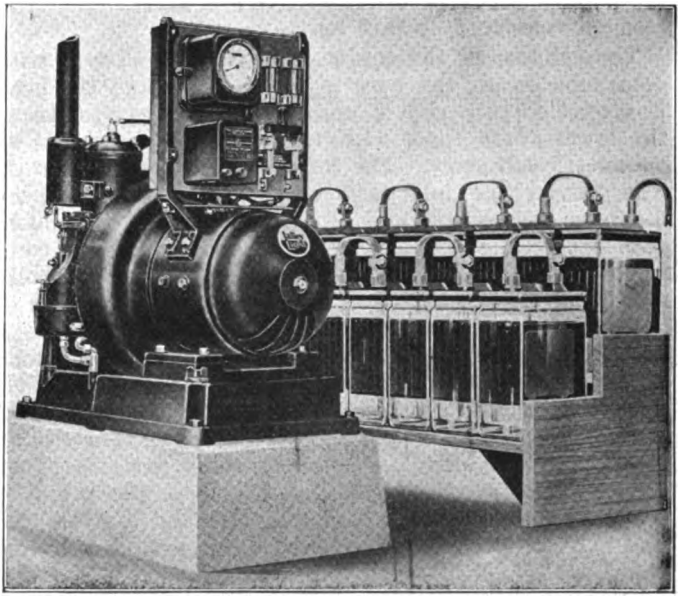

FIG. 9—ANOTHER EXTERIOR VIEW OF THE 32-VOLT SEMI-AUTOMATIC PLANT ILLUSTRATED IN FIGS. 7 AND 8 SHOWING THE STORAGE BATTERY IN PLACE

which is stored in the base. The flywheel is located between the engine and the generator. The generator is of the standard four-pole design and driven by a flexible coupling. The battery has a capacity of 115 amp-hr. Fig. 8 is an outside view of the plant; and Fig. 9 gives a view of the complete installation.

Fig. 10 shows the Merritt plant, with which I am particularly well acquainted. The design follows conventional lines but, while there is nothing of startling originality about it, simplicity and compactness have been made keynotes. The capacity of this 32-volt plant is 1½ kw. at 1200 r.p.m., with an 1800-watt overload capacity for extended periods. It is a plant of the semi-automatic type furnishing power from the battery and generator combined, or from either battery or generator alone. It is composed of a single-cylinder engine of 3-in. bore and 4-in. stroke, direct-connected to a four-pole generator upon which is mounted the switchboard. The engine develops 3¼ b.hp. at its rated speed. This power is available at the pulley located at the generator end of

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the plant and can be used to drive any accessory or implement requiring up to 3 hp.

The cylinder of the engine is of the L-head type with detachable head; the bore is water-cooled and the head is air-cooled to permit a more complete vaporization of the lower-grade fuels with the lowest possible loss of volumetric efficiency. The compression-ratio is 4.1 to 1. The valves, one inlet and one exhaust, have a clear diameter of 1⅜ in. and an 11/64-in. lift. The push-rods are steel stampings, 1 in. in diameter. The camshaft is located in a plane perpendicular to the crankshaft and directly above it. It is operated by a pair of helical gears. The crankshaft is of the bell-crank type and bored through to receive the armature shaft, which also clamps the flywheel against the shaft. The flywheel has 12 blades which form the cooling fan; these are cast integrally on the side facing the radiator. The design of these blades follows airplane-propeller practice. They draw the air through the generator and the radiator, which is located between the generator and the flywheel, and expel it radially through openings provided around the flywheel housing. Cooling is by thermosyphon circulation, a cellular radiator is used and a small water-tank is located at the highest point of the return system to regulate the flow of water. The capacity of the cooling system is somewhat less than 2 gal.

Lubrication is furnished by a gear pump located in the bottom of the crankcase, which forms an oil tank of 1-gal. capacity. Oil is supplied under a pressure of 6 to 8 lb. per sq. in. to the crankshaft main bearings and through a hole drilled in the crankweb to the connecting-rod bearing. The upper connecting-rod bearing and cylinder wall are lubricated by the oil escaping from the main and lower connecting-rod bearings. The generator outboard bearing is lubricated by a self-contained ring-oiler following electric-motor practice.

Ignition is furnished by a tap from five cells of the battery and is of the jump-spark type. A roller timer is used in conjunction with a standard Ford ignition coil having its terminals located on the opposite end of the vibrator. The spark timing is fixed.

A ¾-in. nominal-size carbureter is used. This is merely a mixing-valve with automatic vacuum control for all loads. Fuel is sucked from the engine base, which at the same time forms the fuel tank and has a capacity of 3½ gal. This permits the operation of the

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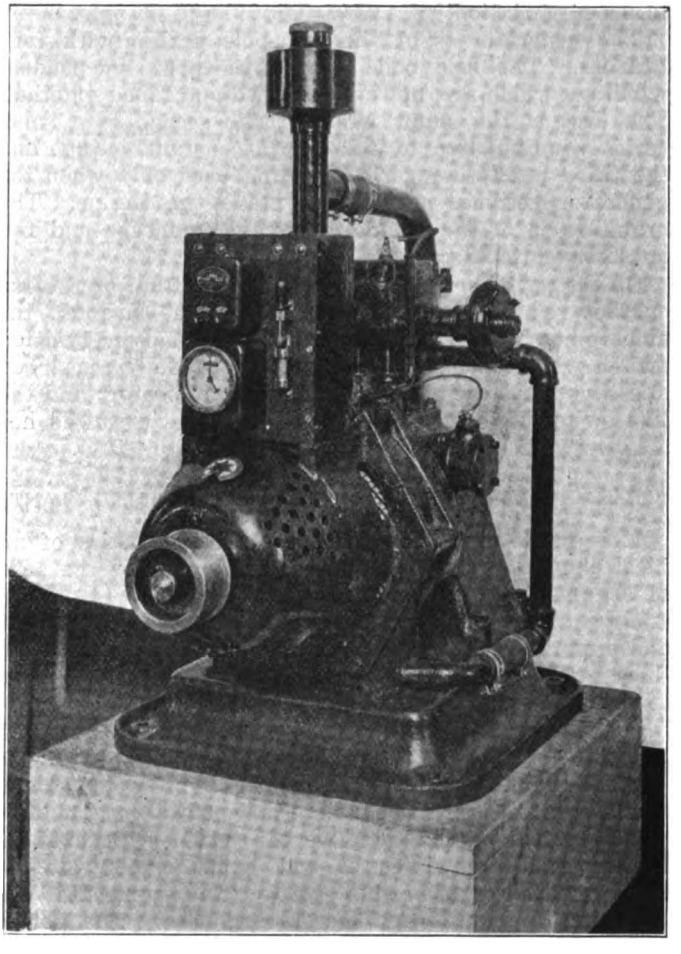

FIG. 10—A 1¼-KW. SEMI-AUTOMATIC PLANT CAPABLE OF FURNISHING CURRENT AT 32 VOLTS FROM THE BATTERY AND GENERATOR COMBINED OR INDEPENDENTLY FROM EITHER ONE

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plant for about 13 to 14 hr. at the charging rate. Gasoline or kerosene is used. With the latter a small gasoline starting tank is provided. The engine speed is governed by a centrifugal governor that is very sensitive to speed variation.

The generator is of the four-pole design with four brushes. The field coils each have three independent windings which are, however, formed and taped together. The first is the shunt winding, the second is a small series winding used to maintain a constant voltage and the third is another series winding used only when the generator becomes a motor to crank the engine. The armature is of the standard drum-wound type and follows conventional practice.

On the switchboard are mounted the cut-out or reverse current relay with its "start" and "stop" buttons; the ampere-hour meter, incorporating an automatic ignition switch which opens when the battery is fully recharged and thus stops the engine; a charging indicator; and the line switch with a 30-amp. fuse. The battery used has a capacity of 120-amp-hr. S.A.E. rating.

Characteristics of the Ideal Farm Lighting-Plant

It is most difficult to define the characteristics of an ideal plant of the type under discussion. For the sake of argument, let us assume a farm of 100 to 140 acres, analyze and tabulate its requirements as to both light and power and then devise the equipment. We can take the 25-watt lamp as the best for all-around use, as that seems to be the most popular size. The average lighting load per day on the farm is approximately as given in Table 1.

The maximum lighting load per hour would occur when all lamps are used simultaneously; but, as this would seldom be the case, we can assume the average lighting load to be sixteen 25-watt lamps, or 400 watt-hr. For a modern farm of this size we can assume that the following appliances and motors are used. The power required is stated in Table 2.

No specific time can be assumed during which one or more of the accessories in Table 2 are used, and therefore this power load is a very variable factor. The power-load values show that the lighting load is the smaller item.

In many instances and for different reasons, barns are located several hundred feet from the farm house. To

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TABLE 1—AVERAGE DAILY LIGHTING LOAD

Location	Number of 25-Watt Lamps	Service Hours per Day	Watt-Hours
Kitchen	1	3.0	75
Dining Room	2	2.0	100
Living Room	3	3.0	225
Three Bedrooms	3	0.5	40
Bathroom	1	1.0	25
Porch	1	1.0	25
Basement	1	0.5	15
Barns	5	2.0	250
Miscellaneous	5	1.0	125
Total	22	...	880

handle these different loads efficiently the lighting plant should be set up where the mechanical and electrical loads are at a maximum, to keep transmission losses at a minimum. The plant must be of the 110-volt type, so that the drop of voltage between the plant and the most distant lamp or accessory will not be sufficient to decrease brilliancy or operative efficiency. Incidentally, this type will permit the use of smaller size wire and standard lamps and appliances. When it is realized that to carry 400 watts a distance of 150 ft. without abnor-

TABLE 2—POWER LOAD OF APPLIANCES AND MOTORS

Household	Power Required, Watt-hours
6-Lb. Iron	600
Toaster	500
Grill	500
Percolator	400
Washing Machine	300
Vacuum Cleaner	175
Sewing Machine	50

Farm in General	Power Required, hp.
Milking Machine	¼ to 1
Cream Separator	¼ to 1
Churn	¼ to 1
Refrigerator	¼ to 1
Water-pump	¼ to 1
Corn Sheller	¼ to 1
Bone Cutter	¼ to 1
Small Drilling Machine	¼ to 1
Forge Blower	¼ to 1
Grindstone	¼ to 1

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mal voltage loss, No. 6 solid copper wire is required for the 32-volt system, the saving accomplished with the 110-volt installation deserves consideration. With the low-pressure system a drop of 4 volts decreases the lamp brilliancy 25 to 30 per cent.

The capacity of the plant should be sufficient to operate all of the accessories that might be used at the same time; also compromising with the charging load to secure the utmost economy. In Table 2 we would have a maximum power-load of approximately 4 hp., representing two-thirds of the farm accessories plus the household appliances such as the electric iron, washing machine and vacuum cleaner. This would mean a 110-volt 22-amp. generator, or 2400-watt capacity at full load. With a charging rate of 4 amp. per hr., the charging load would be two-elevenths of full load.

It must be a battery plant because the lighting load is too small at times to be economically taken care of by the generator. In this instance the current consumption amounts to 400 watt-hr.; or, 400/110 equals 3.63 amp-hr. with the maximum load and 25/110 equals ¼ amp-hr. with the minimum. Battery manufacturers are of the opinion that, for economy and life, the maximum rate of discharge permissible should be slightly less than the rate of charge. This requirement is fulfilled.

We can consider the average life of a lighting storage-battery to be 400 cycles. By the term cycle is meant a complete charge and discharge. Taking a battery of 40-amp-hr. capacity we actually have 30 amp-hr. available before a new cycle needs to be started, the remaining 10 amp-hr. being ample to crank the engine. This means that each cycle will last 30/3.63 or slightly more than eight days. The life of the battery under these conditions will be about eight and one-half years. In practice this would be a guess at best, for the reason that the lighting load is not uniform but changes with the seasons of the year. Another reason for a battery plant is that a battery is needed to crank the engine. Whether it is a 6 or a 12-volt starting battery or a 110-volt lighting battery it must be kept in operation just the same.

The plant must be fully automatic in its operation. It should start as soon as the battery reaches its lowest level and stop when it is fully recharged. It should also start automatically as soon as the load on the battery exceeds the charging rate and stop as soon as such loads are relieved. It must be designed to permit the

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use of the engine power to drive any needed accessories directly. It must be simple, reliable and fool-proof; a machine almost human in its operation. While the plant just described fulfills all the requirements of the average farm it can be made very flexible by increasing the size of the battery to suit conditions.

Design Factors

The last phase to be dealt with is the one relating to the design of component parts. To be explained clearly, this subject must be divided into four parts; the engine, the generator, the switchboard and the battery.

A consideration of the design features of lighting-plant engines shows that no definite practice is adhered to. However, we find that the majority are of the four-cycle single-cylinder vertical type; four cylinders are used for the larger plants. Over 90 per cent of all farm lighting-plants are direct-connected to the generator; belt-driven units are disappearing rapidly.

Regarding cylinder design, we find both the air and water-cooled type or a combination of the two. The latter is a happy compromise, as it permits a more complete vaporization of the mixture and a cooler-running engine. Water cooling is invariably of the thermosyphon type. With air-cooling, a flywheel fan draws the air through the cylinder-head and cylinder and expels it outward. This cooling method seems to be limited to plants of 1000-watt capacity or less. There is no plausible reason for this and the advantages of air-cooling certainly justify development for its use in larger plants. The main problem is to devise a cooling system adequate for any load at a constant speed; this would mean a fan varying its quantity output directly with the throttle opening. The I-head type of cylinder seems to be the most suitable, as it offers the least area of combustion-chamber wall to the flame of combustion. On the other hand, an L-head cylinder can be air-cooled satisfactorily and undoubtedly be made much simpler. The temperature of the walls should not exceed 325 deg. fahr. under full-load conditions; this entails heat-treatment of the material until the molecules assume a state of rest.

As regards valve design, we find almost every type. The poppet valve is used in every shape and form; the Knight sleeve valve, the rotary sleeve and the tapered rotary valve are used. Each of these valve mechanisms has advantages and drawbacks. The general trend seems

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to be more toward greater use of the poppet valve. It is the best-known type and gives the least trouble. Mushroom-type cams with flat-face followers are the rule when poppet valves are used.

In reference to cams, the company with which I am associated carried out experiments to determine the best valve-timing to suit the plant shown in Fig. 10. Two camshafts were made in an attempt to determine the proper valve-timing for maximum power at full load and at 1200 r.p.m. or 800 ft. piston speed per min. The first shaft had the following timing: Inlet opens 10 deg. late; exhaust opens 42 deg. early; inlet closes 35 deg. late; exhaust closes 5 deg. late. The peak of the power curve was at about 1650 r.p.m. The second shaft was timed as follows: Inlet opens 6 deg. late; exhaust opens 40 deg. early; inlet closes 30 deg. late; exhaust closes 3 deg. late. The peak of the power curve was at about 1475 r.p.m. With either shaft at 1200 r.p.m., the difference of power was very slight, but a greater fuel economy was obtained with the second shaft.

Lubrication in farm lighting-plants is provided by splash or pressure. The splash system is used with ball or roller bearings and a low-pressure circulating system when bearings are plain. As in automobile practice, the pump is generally located in the bottom of the crankcase, which forms the oil-tank. A suggestive adaptation of the pressure circulation of oil, without using a pump, is to have the oil-tank separated from the crankcase but connected to it by a ball check-valve or similar device, utilizing the compression of the air by the piston on its downward stroke to force the oil to the bearings. The amount of oil used by a lighting plant having a circulation pressure system is minute. In a 1000-hr. test made with our plant, the oil was never changed; the only thing done during the test was to add slightly over 1 qt. of fresh oil. This test covered a period of seven months and represents about three years of ordinary use on the farm. Upon analyzing this oil, we found that crankcase dilution amounted to about 30 per cent; nevertheless the total wear on all parts was hardly measurable.

The battery system is the prevailing type of ignition. However, most plants designed for export have a magneto. The reason for the use of a magneto is that batteries have to be shipped knocked down and are practically dead. So far as cost is concerned, the magneto

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compares favorably with the battery system, although the latter is somewhat cheaper.

The voltage which gives rise to the current in the short-circuited primary winding of a magneto is alternating, being produced by rotation of the armature; it is at a minimum at low speed, but increases in value with the speed. In the battery-coil ignition system, the voltage is direct and independent of the speed and is at all times equal to the battery voltage. This is the main fundamental difference between the two types of ignition apparatus.

The lighting-plant engine is essentially a constant-speed engine; therefore the battery system of ignition is the most suitable. Another advantage of this type is that its voltage is direct, which makes it possible to vary the duration of the spark to secure the best ignition of the charge. In the plant under consideration now the timing is set to allow the spark to cross the spark-plug points from 30 deg. before dead-center until 5 deg. after, or a spark duration of 35 deg. We found this gave the best results for power and economy, as a certain time is required to completely ignite every particle of gas within the cylinder.

Referring to the proper spark-plug position, I wish to substantiate the statements made by Captain Hallet that preignition can start from two oppositely located points in the combustion-chamber at the same time. When we first designed the cylinder-head, the spark-plug was located on the center line of the cylinder bore and, at full-load running, a disagreeable knock occurred. We reduced the compression-ratio without results. Finally we moved the spark-plug toward the valve side, being careful to clear the bore of the cylinder, so that any escaping oil would not foul the plug. This eliminated the trouble.

Carbureters used on farm lighting-plant engines are of the well-known float-chamber type or are plain mixing-valves based on the vacuum principle or operating in conjunction with a fuel-pump. Gasoline and kerosene are used. The float-chamber carbureter does not meet with the approval of the Fire Underwriters and will probably become obsolete as mixing-valves improve in design. They can be made automatic in operation and can handle any load with utmost economy. Their size can be so calculated as to hold the engine speed down without loss of

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power, in case the governor should fail to operate, thus averting serious breakdown.

Engine governors are of two kinds, mechanical and electromagnetic. The latter operate the throttle-valve by a solenoid plunger, its movement being regulated by the rise and fall of the generator voltage.

Few manufacturers build their own generators. The four-pole design has almost monopolized the attention of American engineers because it seems to be the most adaptable type to the small sizes involved. Pole-pieces are laminated. The field coils have two or three separate windings, depending upon circumstances; a shunt winding, a series winding used only for starting purposes and sometimes a second small series winding to provide constant voltage irrespective of the load on the generator. In plants where no lighting battery is used, but only a small starting battery, the generator is duplex wound; that is, it has a special winding to charge the starting battery. While this tends to reduce the overall electrical efficiency of the generator, using power and light directly from the plant makes up for the loss through the use of the battery.

Real progress has been made lately toward the realization of a reliable fully automatic switchboard, but it is yet at best a very complicated and expensive piece of mechanism requiring an expert to keep it in running order. Automatic control can be secured by two methods. One is based on the variation of the battery voltage or pressure; the other depends upon the actual capacity of the battery, its amperage or volume. The average switchboard of the semi-automatic type is very simple in construction and is generally composed of an ampere-hour meter registering the rate of charge and discharge and the condition of the battery at all times; a reverse-current relay combined with the starting switch, which keeps the main contacts together by electromagnetic action so long as the current flows from the generator to the battery and, when this action ceases, the contacts separate, the plant stops and the charging circuit is thus broken; and a line switch with a safety fuse. In some plants opening this switch eliminates all electrical load from the generator and all the engine power can be used as desired.

Storage-Batteries

The storage-battery is still considered the weakest part of the isolated plant. Much money has been spent by

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battery manufacturers to educate the buyer as to storage-battery construction, installation and care. The cells of a lighting battery are usually of the glass-jar type. Their capacity is determined by the work the battery has to perform. For lighting purposes only the battery should have a capacity of not less than 120 amp-hr. for the 32-volt system or 40 amp-hr. for the 110-volt service. When used for both power and light it should have a capacity of at least 160 amp-hr. for the 32-volt system or 60 amp-hr. for the 110-volt system. These ratings are according to S.A.E. standard; that is, they are based on intermittent discharge. Considerable difference of opinion still prevails as to which is the best battery-capacity rating, the S.A.E. standard or the 8-hr. straight discharge. While the former is better from the engineer's point of view, the latter is much simpler to express, although not so accurate. I merely record the facts and am at a loss to suggest any improvement.

The cost of a 110-volt set of batteries is approximately twice that of a 32-volt set of the same capacity. On the other hand, the loss of potential energy in the line circuit is much smaller in proportion with the 110-volt system. This calls for greater efficiency of the high-pressure type and, incidentally, when energy has to be carried some distance, the cost of the line for the 110-volt system allows a considerable saving over the line cost of the low-pressure type. Battery engineers have established the fact that the charging portion of the cycle of a lighting storage cell has the greatest influence on its life. Under normal working temperatures the positive plates disintegrate much more quickly than the negative plates. Deterioration within the positive plate is due to the loss of active material during the charging period and is known as sloughing. It is a gassing within the plates, producing small bubbles which result from the decomposition of the water of the electrolyte. In general, the slower the charge is, the better it is for the plates, although a high rate of charge is not harmful provided the temperature of the cell never surpasses 110 deg. fahr., which is the maximum charging temperature. It should be remembered also that a charging rate lower than normal causes sediment deposits and reduces the life of the battery. The same thing applies to an abnormally high rate of charge, but to a smaller extent. The best charging rate for the average lighting-battery set seems to be 12 to 14 amp. per hr. for a 32-volt 160-amp.

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set, and 4 to 5 amp. per hr. for a 110-volt 60-amp. set. As the generator furnishes constantly the same amount of watt-hours, the charge tapers off as the voltage rises.

So far as the best discharging rate is concerned, certain battery manufacturers claim that one-half the charging rate will allow the longest life of the battery. A high rate of discharge for short periods does not damage the battery, as seems to be the consensus of opinion, provided the normal section of the conductors is large enough to prevent overheating. It is not detrimental to discharge a battery completely so long as it is not allowed to remain in that condition. The best practice is to discharge the battery until its potential is just high enough to permit easy cranking of the generating unit. A lead-acid cell has a 2.2 to 2.3-volt e.m.f. when fully charged and a 1.7 to 1.75-volt e.m.f. when discharged.

Concerning the nickel-oxide battery, more commonly known as the Edison type, this type of cell is used for farm lighting purposes in only a few instances. I understand that it will stand much abuse, but that it has a high charging rate and an overall efficiency of about 50 per cent. The Edison cell has a 1½-volt e.m.f. when fully charged and a 1-volt e.m.f. when discharged. This means that a greater number of cells are required for the same voltage; therefore, it is a more costly battery.

I hope I have made clear the importance of the farm lighting-plant and its present position in the automotive industry. While I have not attempted to cover the subject from every angle, I have dealt with its most important questions and expressed my own opinions. In conclusion, I wish to emphasize that, while rapid strides have been made in the past, there still remains a great deal to accomplish as regards stability of design, reliability and economy.

THE DISCUSSION

H. D. SHAMBERG:—What is the proper size of a plant for general use on a farm? It seems to me that if a small article like an electric iron requires 600 watts to operate it, a plant of say 750-watt generator-capacity would hardly be large enough for general farm utility; especially if more than one of these articles were used at a time and lights also were required simultaneously.

CHARLES FROESCH:—I think the best size of plant for a farm is between 2 and 2½ kw. A plant of 1½-kw. capacity is a fairly good size, but it does not answer for

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the larger farms; it would be too small for general purposes. On the other hand, it would not be fair to design a plant to operate just one accessory or appliance that used 600 watts. The plant would be very inefficient, because a gas engine is not efficient when working under very light loads.

A MEMBER:—Are not most of the plants sold today of the smaller size?

MR. FROESCH:—Farmers are willing to buy a plant of larger size now. The tendency among them is to buy a larger plant even though it costs more. The larger plant has been demonstrated to them in a favorable light. Regarding the cost of the plant, the burning of two 25-watt lamps averages about 0.8 cent per hr.; using kerosene it amounts to 7 cents per kw., when kerosene is 18 cents per gal. With gasoline at 35 cents per gal. the price would be between 12 and 13 cents per kw.

A MEMBER:—Is depreciation included in that price of 12 to 13 cents per kw.?

MR. FROESCH:—No, that is simply the cost of the fuel.

JOSEPH TRACY:—What is the power output of these plants per gallon of fuel?

MR. FROESCH:—About 500 watts; the consumption is about 1 qt. of fuel per hr. and the charging rate is 15 amp.

MR. TRACY:—You mentioned that some of the 75 different types of plant on the present market run without a battery; what is the approximate proportion?

MR. FROESCH:—Two plants are run without batteries; the remainder are all operated with batteries.

DR. RICHARD H. CUNNINGHAM:—Is the isolated plant adjustable with regard to the kind of fuel to be used?

MR. FROESCH:—When the machines leave the factory they are adjusted for gasoline, but there is an adjustment on the mixing-valve so that, by turning the valve, the plant will run on kerosene.

VOLTAGE REGULATION

C. M. MANLY:—I encountered the first isolated electric plants some 11 years ago when several companies were building 15 kw. and 25-kw. outfits for Army fortifications. They had to contend with the important matter of regulation. How closely is the voltage being regulated at present? The Government had very stringent specifications in connection with that between no load and full load. The tests that the generator and the entire outfit

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were put through in throwing them suddenly from full load to no load and back to full load were very severe. Voltage regulation was apparently the greatest trouble they were having at that time. Some companies seem to be producing outfits for commercial service that are perfectly satisfactory.

MR. FROESCH:—I am not in a position to throw very much light on that subject. On this little plant the only voltage regulator is a small series winding. I understand that some plants regulate their voltage with a solenoid plunger; that is, electromagnetically.

MR. MANLY:—How much voltage variation is there between no load and full load?

MR. FROESCH:—The voltage varies from 32 to 38 volts.

MR. MANLY:—How much voltage variation would there be on the 110-volt circuit? Have you built any 110-volt outfits?

MR. FROESCH:—No, we have not; but the difference must be greater because the National Gas Engine Association recommended that the plant must run to 125 volts at full load.

H. CARLTON:—In building our isolated electric plants we have left off all governing arrangements; we have no special voltage control on the generator. We depend entirely upon the combination of the battery and the generator action to maintain the proper speed. We find that in this way we get approximately 2½ per cent voltage variation from no load to 25 per cent overload. In other words, it is a voltage variation that will barely give a flicker to the lights. We consider that this method has worked out well.

MR. FROESCH:—For export plants I advocate the use of a magneto because the battery is practically dead. However, if the total pressure of the battery is utilized there will be a sufficient potential to provide a spark for the engine ignition.

MICH E. TOEPEL:—Will the potential be sufficient for starting?

MR. FROESCH:—Yes.

MR. TOEPEL:—For what duration of time?

MR. FROESCH:—For a few short starts only. It depends upon the capacity of the battery.

MR. MANLY:—About the shipping of the batteries, what was the outcome of the proposition of shipping storage-battery plates fully charged and dry?

MR. FROESCH:—Some manufacturers did that, but they

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found that as soon as the plant was assembled the plates burst.

CARL F. SCOTT:—The great factor in the development of isolated plants was the tungsten lamp. It reduced the energy required to an extent that made possible a great amount of lighting from a very small engine and generator. A second great factor in pushing the business among farmers was the stress placed on "power" rather than on "lighting" features, because the possibilities are enormously increased by the use of power on the farm, as compared with the use of the light alone in the farmhouse.

With the larger plants, in connection with the increased cost of operation, is there not a tendency toward 110-volt plants that have only a starting battery and get along without a large storage-battery? Have we realized the possibilities of increasing the speed, decreasing the cost and increasing the efficiency? Is the time coming when these plants can be run at full load, inside a room, so noiselessly that they would scarcely disturb a conversation? Regarding automatic control, is not the tendency toward a plant that starts up when the first device is operated and shuts down when the last device is turned off?

MR. FROESCH:—There are only two batteryless plants on the market now. They do not seem to be very popular with the farmers. One of the main troubles is that sometimes they start and sometimes they do not.

With regard to noise, lighting plants are continually being made quieter. This plant is somewhat noisy because it is hand-made and not a straight production job. We have made only about 17 machines of this type, and do not expect them to run very quietly. The fact that a plant has a higher speed does not decrease the cost of the plant. It must be made more accurately. It seems that the lower-speed plant prevails on the market. I believe in the high-speed plant, but it seems that the majority of the plants today run at 1200 r.p.m.

Regarding automatic control, very few such plants have been placed on the market. There is a tendency toward plants that start automatically, but sometimes they do not start, as I have said. A reliable automatic switchboard has not yet been designed, although it is the proper thing. Such a switchboard must be simple, because simplicity means reliability. It is hard to get, but we are coming to it. It must be remembered that this

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type of installation is very young. We have been working hard on it. Previously such plants were simply makeshifts. No research work was done along this line until the last two years. A great many plants have been manufactured lately.

Controlling Devices

Mr. Shamberg:—With reference to the full-automatic feature, it is a disadvantage to have a plant too completely automatic, because the owner is not likely to give the plant sufficient attention. The semi-automatic plant which is started merely by pressing a button can be designed with the starting switches at remote places. For instance, a second starting button can be put upstairs in a house, if the plant is in the basement.

Mr. Froesch:—I believe that one manufacturer puts out a meter which starts the plant automatically as soon as the load is greater than the rate of charge of the battery.

Mr. Carlton:—We watched the automatic system for some time and found that it involved considerable delicate apparatus which necessitated repeated inspection by persons who knew the apparatus. As a result, we produce a non-automatic plant that is started by the battery after pushing a button and stopped by a push-button also. We followed that practice to reduce the plant to the simplest form. We felt that it would be a safer plant to put into the hands of inexperienced persons; that there was a better chance of its being properly maintained. We do not see that it is necessary to put an automatic stopping device on an electric generating plant, any more than on an automobile starting and lighting equipment. The conditions are the same in every way.

Mr. Froesch:—The automatic feature of the ampere-hour meter is good. It is very reliable, and it eliminates the human element. It is possible that the farmer will run the plant too much and overcharge the battery.

Mr. Carlton:—The protection that we have installed is in limiting the amount of fuel. The operator can fill the tank full of kerosene, start up and let the plant run until the fuel is gone. We think that is a fairly safe feature. No expert inspection is necessary.

Mr. Froesch:—How can the exact condition of the battery be determined?

Mr. Carlton:—We believe the only proper way is by using an hydrometer.

Mr. Froesch:—We recommend that users examine the

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condition of the battery with an hydrometer monthly, and from that reading check up the ampere-hour meter. It can be done very easily.

W. S. BOULT:—One firm guarantees its meters to be electrically correct for one year. During the year, if anything happens to the meter, the customer need only take it off and send it to the factory. The same would apply at the end of the year; there is no charge for testing it.

FRED W. ANDREW:—We should understand that in charging the battery and discharging it there is always a loss. I had something to do with the Delco system in the early days and we took this loss into consideration. I think the instruction book said that the ampere-hour meter was to be checked up with the battery by using an hydrometer about once monthly. I fail to see how that condition could change.

MR. BOULT:—On the base of the ampere-hour meter we have a resistor that can be set for rates for overcharge of the battery ranging from 10 to 20 per cent.

MR. ANDREW:—One can charge the battery at a certain efficiency, but in discharging it one never gets out all that has been put in. Of course, the ampere-hour meter cannot take care of that ordinarily. Is there some device which automatically takes care of that discrepancy? As I see it, that must be set from an hydrometer reading at frequent periods.

MR. FROESCH:—The charging and discharging records from the ampere-hour meter are not the same. The needle travels 20 per cent more slowly on the charge than on the discharge. That is the reason we advise the monthly calibration of the meter.

E. J. BARNEY:—The resistor is a device used for keeping the ampere-hour meter in step with the battery so far as is possible but, over the wide range of load that it operates, there will be a slight error at about the end of a month. We take care of that by asking the user to charge the battery fully and to set the hand of the ampere-hour meter in the proper position once monthly.

A MEMBER:—I had my first intimate acquaintanceship with the isolated charging plant last summer. I found a battery in a country store that needed to be cleaned. The sediment had accumulated so that it came almost up to the bottom of the plates. Is the depth of the battery cells made sufficient to take all the sediment or, in general, must the battery be cleaned before the plate's life is entirely gone?

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MR. FROESCH:—The battery should be inspected regularly.

MR. ANDREW:—The Koehler plant has a small four-cylinder engine and it operates by turning on or off whatever device one wants to use. The only battery used is a 24 volt battery for starting purposes, but this does not carry the load. Whether it operates well, I do not know.

In regard to ignition, you stated that the battery-ignition spark was on for 35 deg. Do you mean that the spark continued 35 deg.?

MR. FROESCH:—Exactly.

MR. ANDREW:—You do not mean that the build-up of the coil is for 35 deg.?

MR. FROESCH:—No, the duration of the spark is for 35 deg. in the plant.

MR. ANDREW:—How do you obtain that?

MR. FROESCH:—With a coil; it is a succession of sparks.

MR. ANDREW:—Do you use that vibrator continuously?

MR. FROESCH:—We use it for 35 deg.

MR. ANDREW:—Is it used like the old Ford vibrating coil?

MR. FROESCH:—Yes.

MR. ANDREW:—Do you have any trouble with the vibrator?

MR. FROESCH:—We have no trouble whatever.

MR. ANDREW:—Why is a water-cooled engine used for this work? When the Delco lighting system was first put out, we went over air-cooled and water-cooled engines very thoroughly. We concluded that a lighting system of this kind was likely to be installed in places where freezing might occur in winter. That is why Delco used an air-cooled engine, and why I am personally in favor of an air-cooled engine for that type of apparatus. If Mr. Froesch favors an air-cooled engine, why does he show a water-cooled engine?

MR. FROESCH:—Engineers are choosing the path of least resistance and such is the case in this instance. The air-cooled proposition is better, but it requires more research work.

MR. ANDREW:—I think there is no question that the air-cooled engine is about to come into its own, because of the scarcity of fuel and the fact that it can be run with greater efficiency than a water-cooled engine. I have never been able to make up my mind that the 32-

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volt system is right. One can buy apparatus for the 110-volt system anywhere in the country.

THE 32 AND 110-VOLT SYSTEMS COMPARED

MR. FROESCH: — The 32-volt system is pretty much standardized in the country now.

MR. ANDREW:—It surely is not standard in foreign countries. A number of Delco lighting plants were shipped to South Africa. Battery supply houses are scarce there. That is one of the reasons exporters prefer a magneto on the engine.

MR. FROESCH:—The first plants made were 32-volt; they included only a plain generator, a set of batteries and a switchboard. Why the battery manufacturers who made the plant chose that voltage I do not know, but it was the most popular type at that time.

MR. SHAMBERG:—I believe the reason for the 32-volt system is the initial cost. It requires only a 16-cell battery, whereas the 110-volt system requires a 56-cell battery. The latter would cost considerably more.

MR. ANDREW:—That is true, but batteries are not necessary. Should we or should we not use the 110-volt system?

MR. SCOTT:—I agree with Mr. Andrew. A 20-hp. engine and starter, a battery and accessories can be bought for about $510. The system described here costs about $645. Why is it not possible to have a system capable of more than ½ kw. without batteries and without more than the most rudimentary type of switchboard? Two years ago I made a lighting system for a country house. I used an air-cooled motorcycle engine and a small generator. About 11 p. m. we would shut off the switch. It ran for two summers. I suppose it had intelligent care, compared to the ordinary powerplant maintenance on a farm. It cost about $150, but perhaps would have been too crude to meet the ideals of the modern farmer.

There seem to be distinct possibilities in a 110-volt 60-cycle alternating-current light and power system operated without a battery. Such an equipment would use an 1800-r.p.m. single-cylinder engine fitted with a starting motor, generator, battery and switch of about the type used in a Ford automibile, or even smaller. The entire combination of generator, starter, battery and switch for this car can be obtained today for about $85. Thus the starting and excitation features would be a small item in the total cost. Such a generator and starting battery

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would be ample for exciting the fields of the alternating-current generator, which would be of the synchronous type. The generator could be constructed at a lower cost than the present direct-current generators, and the equipment would have the advantage of utilizing standard 110-volt lamps and devices and standard small 110-volt alternating-current motors, which have been developed to a very great degree of efficiency for all classes of work.

The only problems then connected with this system would be those of voltage regulation and automatic control. With the separately excited field, the problem of voltage regulation for varying loads would be no greater than that experienced on an automobile lighting generator at varying speeds. Granted a reliable starting and stopping switch for putting the plant into service when the first device is turned on, and stopping it when the last light or motor is turned off, we have a system that should be materially lower in first cost than those now offered; one entirely lacking in the objectionable features of the large battery; one adapted to transmit power greater distances without too great a relative voltage drop; and one using devices applicable to any standard power service equipment. Farmers would be more ready to install such systems, because of a realization that when central-station power came to their district at a later time, a large part of their own electrical installation would still remain standard.

MR. YOUNG:—When generator sets are manufactured in quantities comparing with the production, for instance, of the Ford motor car, I think they can be produced at a much lower cost. The present price, however, is comparable with that of other apparatus built in the same quantity.

O. A. ROSS:—Referring to the suggestion just made to employ 60-cycle alternating-current generators, it must be remembered that the field of these machines is separately excited by a direct current. For this reason, a direct-current generator or a storage battery would be required. In the latter case a generator would be required to charge the storage battery. It is necessary also to regulate the field current with any change of alternator load; this, of course, can be done automatically. It seems to me, however, that in place of simplifying, the use of alternating-current generators adds complications to the isolated electric-lighting plants under discussion.

ELMER H. SCHWARZ:—Probably those who have spoken

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in favor of doing away with the batteries have forgotten that the average farmer does not run his plant all the time; the battery is needed to supply lights when the generator is not running. In case of a shutdown of the gas engine, the batteries are in reserve. I think that is the main reason batteries are used. One of the possible explanations of a 32-volt system is that train lighting had come to 32 volts, after a try-out of 80 and 60-volt systems. On account of this experience, undoubtedly, the 32-volt system was found to be the most practicable, mainly, I suppose, from the standpoint of the storage battery.

HENRY C. MCBRAIR:—In reference to the alternating-current system, is it not a fact that the General Electric Co. built a compact three-phase machine, and a type "D" machine called a "compensator" which had a small combination generator and alternator for exciting it; but that it abandoned them about eight years ago, and then used a separately-excited direct-current machine, which required an extra-small generator on the end of the alternator? I should say that this would be too complicated a proposition for a farm.

MR. ANDREW:—I think Mr. McBrair has answered the question. It is not a very difficult matter to build a separately-excited generator of small size and constant speed which can be used for farm lighting. To make it fully automatic, it seems to me that the final article in this line would be an air-cooled engine with possibly a 110-volt 60-cycle alternating-current generator.

MR. BARNEY:—How will the voltage regulation be provided for on the alternating-current unit that has been suggested? It will mean the addition of some complicated mechanism, such as a Tirrell regulator. Anyone acquainted with alternating-current machinery knows that such a regulator is used in powerplants for regulating purposes.

JOSEPH A. ANGLADA:—Farm-lighting maintenance resolves itself into the same proposition that we have with automobiles. We buy an automobile and for perhaps the first two months we take care of it regularly; during the second two or three months we devote less attention to it; finally we decide that the car needs no attention. With the farm-lighting outfit, the farmer puts the machine down in the barn to avoid its noise. The farmer with the non-automatic outfit finds it troublesome to go out and shut the machine off. We know that the two-

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cycle engine is a cheap one to build. It seems to me that a 110-volt, automatic, non-battery system is what we shall use eventually, just as we have adopted simplicity in automobile construction.

MR. FROESCH:—The question regarding the use of the two-cycle engine for lighting plants is very logical but, if we wish to use the plant to charge the batteries and also have a sufficient capacity to operate small appliances, the charging load will be very small compared to the full load, and it is well known that with a two-cycle engine it is too severe. You must make it small, so that the charging load will be high enough to permit good scavenging of the cylinder.

MR. CARLTON:—With a 110-volt system or with any other system without a battery, how will night-light conditions be met, such as a few lights for all-night service or a bathroom light? Without the battery, we must keep the engine running all the time we want light. With a battery this is taken care of.

MR. ANDREW:—It is already taken care of. The machine has to run, it is true, but it can be shut off at any time, right in the house, and without having the battery system carry the load.

FUELS

H. H. BRAUTIGAM:—Will Mr. Froesch give us his views regarding the fuel problem? We have not yet really developed a perfect-running kerosene engine in the automobile or in the marine field. In the operation of isolated farm lighting systems, we have a constant load and a more favorable condition. We can operate on fuels which cannot be used in the automobile field, such as kerosene. But will the lighting outfits that are being put upon the market to run on both gasoline and kerosene be successful in the long run, and will they give satisfaction to the purchasers? We know that kerosene requires special arrangements for vaporization. We must contend with more carbon in the cylinders, more dirty spark-plugs and more or less unburned fuel going down past the piston and collecting in the base of the engine. Every lighting outfit on the market today is put out to run on gasoline. All claim, however, that the outfits can be run on kerosene by making slight changes and different adjustments.

MR. FROESCH:—The Delco plants have been very successful in using kerosene for fuel during the last two years. We have been using kerosene to a great extent,

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and we have found less carbon deposit with it than with gasoline. The carbon deposit we had with kerosene was gumlike; what we had with gasoline was solid. I cannot explain readily why this happens. I have not had time to investigate it. But it is a fact that we find the plant will run more successfully on kerosene than it will on gasoline.

WILLIAM E. KEMP:—Our experience has been that under certain conditions kerosene can be used as successfully as gasoline. It is my opinion that the single-cylinder engines used for isolated electric generating plants most nearly approach an ideal condition, principally because we can use the heat generated by the engine to better advantage, and also avoid the difficulties usually encountered in multi-cylinder engines wherein long intake manifolds are needed.

There are numerous methods of applying heat to the mixture but, where the design has permitted, we have invariably obtained a higher efficiency by using a form of intake manifold, integral with the exhaust, that has caused the heavier particles of fuel to be impinged and retained against hot surfaces, and also permitted the lighter particles to be carried to the combustion-chamber at a lower temperature, thereby decreasing the volumetric losses due to expansion.

H. W. SLAUSON:—The sales possibilities of these plants are not limited to the farm. I do not live on a farm. I pay 12 cents per kw-hr. for electric light. If I could get it for 9 cents, I would consider buying one of these isolated plants. Many people in this country have summer homes where such plants can well be used; at the seashore, the mountains or on small private estates. We should have a name for a plant of this kind that is more comprehensive than "farm lighting plant" or "farm powerplant," one that indicates its possibilities as a producer of power and light for every kind of house or service situated too far distant from the main power-current source. Regarding the power take-off on this particular plant, are there many conditions where it is better to use the power take-off than an individual electric motor?

MR. FROESCH:—Whenever it is possible to use a direct power take-off, it is advisable because it is not necessary to use batteries. Battery efficiency is between 75 and 85 per cent, but is about 75 per cent in most cases. I advocate the use of batteries for light and for small

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household appliances such as electric irons, but whenever an electric motor is needed a power take-off is more economical if it can be used.

MR. BARNEY:—In sections producing natural gas, I think most farm lighting plants could be operated on natural gas. In West Virginia, Kansas and Oklahoma natural gas can be obtained at from 20 to 30 cents per 1000 cu. ft. The average unit might, I think, be expected to deliver between 25 and 30 kw-hr. per 1000 cu. ft. That would cut down the operating expense.

E. FAVARY: — Does Mr. Froesch recommend any changes in the design of the engine when kerosene is used as fuel?

MR. FROESCH:—The main feature in this engine which is different from the automobile engine is the use of a bell-crank type of shaft. The connecting-rod follows standard design and so does the remainder of the engine. The only difference probably in this engine between gasoline and kerosene for fuel is that the head is air-cooled, resulting in vaporization. I think it vaporizes kerosene just as well as it does gasoline.

SERVICE

G. W. WARD:—I have sold many farm lighting plants and recently have visited the factories of many different manufacturers. Service is one of the biggest problems that the farm lighting industry has to contend with. These plants are placed on farms where they will be stationary and it will not be easy to give them attention. It is well worth while to begin right now thinking along that line. A plant must be as nearly fool-proof as possible. These plants are going into isolated places. They will be forced to function under all kinds of conditions. Last fall I traveled 700 miles through Maine and found many farmers who had installed isolated plants but gone back to kerosene lamps. Many of the plants were of good design; others were of the old belt-driven hand-regulated type. The trouble was that the plants had not been serviced and the men who had sold them had left the district. No one manufacturer was to blame; half a dozen different firms were responsible for the condition. Later I was told that the manufacturers could not afford to render service. I found the same problem in another locality. We must standardize. Service must mean a certain thing; today it does not in the minds of the distributor and dealer. If the isolated-plant manufacturers

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will agree on what constitutes service and what their guarantee is to be on a plant, stick to it and insist that dealers and distributors do the same, we will eventually have the condition of a distinct class of men servicing plants in rural communities. Then the big problem that is retarding the industry as much as any one thing will have been solved. Many dealers are obliged to give up the sale of isolated plants because attempting to keep the plants in operation would take away a large part of their income.

C. W. DEAN:—The chief trouble with farm lighting-plants is that the majority of salesmen sell the farmer too small a plant for the work desired or required by the farmer. The salesmen, eager to make sales, will guarantee service for one year and guarantee other matters they will not be able to live up to. In other words, they guarantee the farmer an engineer for one year. The word service has been much abused. No manufacturer can sell an isolated electric plant for $645 and guarantee an engineer to maintain the plant for a year.

A full-automatic electric-lighting plant without batteries is impossible with present inventions. A full-automatic electric-lighting plant wth a starting battery only is possible, but it is not satisfactory at present. The addtional cost of copper for installation must be considered. It would cost practically as much to run one light as it would to run 10 lights. The engine would be running to use one light just the same as it would for several lights. This would require starting up the plant often, waste fuel and use the automatic electric starting devices beyond their capacity or guarantee. It is no more possible to have a full-automatic electric-lighting plant without batteries, than it is to have a telephone, telegraph or wireless system without them. It is a known fact that all these systems have both batteries and generating sets.

Referring to a demonstration I saw in North Carolina, a plant had a 12-volt starting battery with a return wire run from each light back to the battery. When a light was turned on, the automatic cut-in would connect the generator with the battery and start the engine running. A 20-watt light was used and 15 of them were on one circuit. The negative wire was run the entire length of the lighting circuit to the main-line switchboard. There was a wire from each light to the positive side of the battery, thus making 15 return wires to the battery. I

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was the lowest bidder by $700 on a lighting plant for a building. I submitted proposals on a 3-kw. system with a 56-cell battery. One of my competitors submitted proposals on a 1½-kw. full-automatic plant, using a 12-volt starting battery.

MR. YOUNG:—Regarding the size of the isolated plant, I agree with Mr. Froesch that we should endeavor to make it 1½ kw., with an overload capacity so that certain extra appliances can be connected. The greatest difficulty in that respect has been that, with a small plant for lighting, the owner loads it up with curling irons, fans, smoothing irons and other additional electrical apparatus, and immediately gets into difficulties.

MR. BARNEY:—Concerning the life of the isolated plant, even more than five or six years of service can be expected of them. I know of some units that have been run between 17,000 and 20,000 hr. on test. Compared with the life of an automobile in actual running hours, this is very favorable. Allowing 10 hr. running time for a plant per week, the life of a plant should be much longer than five or six years, as Mr. Froesch's experience indicates.

MR. FROESCH:—The battery wears out in four or five years sometimes, but I have known instances where they have lasted 10 to 12 years. This depends largely on maintenance. With good care, the battery will last probably as long as the plant, but in the majority of cases the battery must be replaced before the plant.

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NEW ENGLAND SECTION PAPER

AUTOMOBILE BODY CONSTRUCTION

By P E Stone[1]

The paper is devoted more especially to enclosed body construction, with the object of creating a closer relation between the chassis and the body designer, from the viewpoint of an automotive body constructor.

After enumerating what are probably the most important materials that enter into enclosed-body construction, inclusive of glue, the author outlines what constitutes the proper seasoning of wood, this being very important because very little all-metal or steel construction has been developed as yet for enclosed bodies, owing to the fact that many parts are required that necessitate using wood. Chassis deflection is discussed in its relation to enclosed-body construction and an outline is presented of body-construction development in general. The author believes that body construction will not be changed radically until either the basic type of design or shape is transformed or there is a firmer foundation to build upon.

Automobile body construction is about to enter upon an advanced state of development. Sales depend upon the appearance and comfort of motor cars, chassis are becoming better standardized and the popularity of the enclosed type of automobile body is growing. This paper is devoted more especially to enclosed body construction, with the object of creating a closer relation between the chassis and the body designer, from the viewpoint of an automotive body constructor.

Few books have been written on the strength and desirability of materials for an automobile body and its members, and they are not of great value. I shall enumerate, therefore, what are probably the most important materials that enter into the construction of the enclosed type of body. The different kinds of wood used include ash, yellow poplar which is commonly misnamed white wood, birch, maple and the cheaper kinds, depending upon the grade of body that is to be built. Aluminum of Nos.

[1] M.S.A.E.—J. B. Judkins Co., Merrimac, Mass.

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14, 16 and 18 B. & S. gage is employed; this is 98 per cent pure aluminum, one-half hard. Steel, of automobile body drawing ductility and of Nos. 20, 22 and 24, B. & S. gage, is utilized. Very little long terne or lead-coated steel is used for body purposes. Cast aluminum is sometimes used. Plywood and composition material are the most important of the less used materials. Plywood was used considerably in automobile body roof construction several years ago.

The most important of the glues is hide glue, some of which is treated for moisture proofing. Others are casein, blood-albumen and fish glues. The casein and blood-albumen glues are considered the best, but as yet they are not entirely dependable and must be mixed and used by an expert.

The Proper Seasoning of Wood

The piling and drying of lumber is especially important in connection with body construction. The lumber should be piled with great care from the time it is green until it goes into the final assembly of the body. Lumber often is piled in a damp place, or upon an uneven foundation, or is not properly spaced. If piled solidly, an unevenness often develops and a twist or wind is given to the board. This results later in a permanent set which can be remedied only by properly steaming the piece in a dry kiln at additional expense. With proper care used in piling and proper foundations and spacers of equal thickness on each tier, one placed directly above the other, a great saving is effected and a better product is secured. If boards have a permanent set that has not been relieved, they will be undersize when dressed or, if sprung into shape, a twist will eventually result in the member in which such a board is used.

Let us consider the methods of seasoning wood. Lumber salesmen will say that air-dried lumber is bone dry. In certain parts of Mexico, air-dried lumber means lumber that has come to the condition of the surrounding air. It will show a moisture content of about 5 per cent by weight. Again, in certain parts of the United States, air-dried lumber will contain 20 per cent of moisture. Therefore, if an automobile body which has been manufactured of air-dried lumber in a moist climate is sent to some locality in a dry climate, the lumber will shrink from 3 to 5 per cent across the grain. Hence, any bolts which have been used in its construction probably could

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be tightened one or two turns, depending upon the thickness of the material and the thread size. As soon as a bolt becomes loose, it causes a creak in the body, paint cracking and chipping, and other general troubles.

The dry kilning of lumber probably is the most important phase of lumber seasoning and it is also just as delicate an operation as the hardening of steel. Very little is known generally about dry kilning. When lumber is properly dry kilned and is not killed during the process, it is probably stronger and of a more uniform moisture content than lumber that has been air dried in the pile. After considerable experience in manufacturing airplane propellers, I think that lumber dried to a moisture content of from 8 to 10 per cent will give the best results for all conditions of atmosphere, because the moisture which is absorbed after the wood has once been dried is not so detrimental as the shrinkage. Probably, only a small percentage of the dry kilns used in automobile-body building plants could pass the Government specifications for dry kilning. Very many of the automobile body builders are still using the old fashioned hot or dry box. A pamphlet entitled Information for Inspectors of Airplane Wood, prepared at the Forest Products Laboratory of the United States Department of Agriculture, is available for those who are interested in the proper drying of lumber.

Metal Bodies and Construction Features

All-metal or steel bodies are made only for open-car types. Very little all-metal or steel construction has been developed as yet for enclosed bodies, owing to the fact that many things, such as tacking rails for upholstery and window regulators, are required which necessitate using wood. Further, enclosed bodies have not been built in large enough quantities to warrant the expensive dies which would be necessary for all-metal construction.

With regard to the actual construction of automobile bodies, the day has past when the woodworker in the body shop was given an outline draft, selected the stock from the lumber pile, made his own patterns, located the mortises and tenons and used the band saw, planer and other machines, completing the whole process himself. Today, the draft must be made so that the mill can get out the stock without seeing the draft as a unit; also, the shapes of each piece must be changed sufficiently to

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allow the mill machinery to reproduce it without too many separate operations and set-ups. These pieces must be constructed so that they can be assembled into units, such as backs, quarters, doors and roofs, and can finally be put together without a great amount of fitting. In fact, the draft as a whole does not leave the draft, pattern, layout and dressing-box rooms. Each man in the shop does only his own part. Where only two men touched a body in the body shop under former conditions, 25, 50 or more, may participate in its construction at present. This specialized construction is and has been developing many new machines for the mill. It also places a certain handicap upon designing. The methods of construction have been changed completely within the past 10 years.

In body construction, the draftsmen should have not only careful and accurate measurements of the chassis, but they should know the maximum amount of deflection, plus and minus, of the chassis frame from front to rear. They should know also the amount of wind or twist of the chassis. Neither of these factors has ever been defined, to my knowledge, but the construction has to be made so as to take care of both. This lack of necessary information has caused much trouble. It has produced body creaks, rattling doors, excessive up-and-down play of the doors and the opening of body seams.

Chassis Deflection

When you ride in a car with an open body with the top raised and are badly jolted you sometimes hear the material of the top snap. This is good proof of whether a chassis frame twists or deflects. The top first loosens and then snaps tight. This is more in evidence when the top is of the old cape type. Also, the doors move up and down. In a rigidly constructed body with roof rail, the body must withstand all of these strains. Again, the chassis designer fixes the steering column both to the chassis and to the instrument board in the body, which is placed 24 to 36 in. further back on the chassis frame. Strike a rut and the frame deflects; the instrument board creaks and twists, or the steering column bends; otherwise there must be a very rigid construction that ties these three parts together. If the chassis frame deflects down and then up, a tension or a compression force is set up in the roof rail because the center of bending is either above or below the frame. In most of

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the slanted fronts there is a triangular support which does not allow the front pillars to bend. This either directs all the thrust to the back of the body or transfers the thrust down into the cowl. It is more than likely that this thrust causes many cowls and front pillars to give trouble above the belt on coupés, sedans and four-door inside-drive bodies.

In fastening a body to a chassis frame, sometimes the body sills are placed directly on the frame. The body may be fastened on angles or lugs, three or four to a side, and from 2 to 4 in. from the outside of the frame. This introduces a third strain on the body, as there is a slight twist introduced into the side member of the frame which results in a twist of the body sills. The argument in favor of this method is that it eliminates the squeak between the body sill and the chassis frame, but the mounting of the sill directly above and on the frame, with proper separating material, will usually give the best results. These are a few of the difficulties, but they are beyond the control of the body engineer.

With regard to the constructor's difficulties, let us first consider the body as a mass, concentrated at one point. Such a point would be located from one-half to three-quarters of the length of the wheelbase from the front and from 36 to 60 in. from the ground, dependent upon the style, size and shape of the body. If the front wheel strikes an obstruction, although part of the shock is absorbed by the rubber tires and part by the chassis springs, there is still the inertia of the body as a unit to overcome. Since the force is dependent upon the speed as well as upon the mass, enormous strains are exerted in the joints of the body at high speeds on some rough roads. This force can be divided into vertical and horizontal components. The horizontal component is the one which produces serious effects upon the body construction. The cowl and windshield are at the front and there is very slight chance for heavy or rigid construction, owing to the fact that the driver must have as much unobstructed vision as is possible; also, the pillars, from the belt up, tend to bend and they must overcome a large part of this horizontal force. If it is a slanted-front construction of a rigid type, this force is transmitted down into the cowl and causes squeaks, rattles and cracked panels.

One way to lessen this horizontal force is to lower the center of the mass and make the roof construction as

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light in weight as possible. On straight front bodies, it is a good method to taper the pillars from 1 to 3 in. from the belt rail up. On slanted-front bodies it is good practice to provide a rigid construction and have a member following the angle of the windshield to the chassis frame as near as possible. It is possible to have the front of the body strong enough to withstand this horizontal force, and the reaction may be transmitted to the back of the body and cause open joints.

Development Possibilities

There is considerable opportunity for development along the following lines. Springs should be designed to allow the same elasticity for two as for seven passengers. This would result in less strain on the body. Hard, stiff springs shake and jar body joints. The frame might possibly be designed with a subframe of the full body width at the outside of the sills, cross-braced not only to support the transmission but to eliminate as much twist and wind as possible. At some future time we may build the body and the frame as a unit, possibly using I-beams instead of channel irons.

The progress that is being made in automobile body construction includes a heavier cowl construction, together with the use of heavier gage aluminum and more spot-welding or reinforcements. In the larger body plants great care is being used in drying lumber. Roofs are being constructed that are lighter in weight and of materials that will cause less drumming, or resonance. Slat construction is used in many different forms; it is covered with woven material or leather. The trouble found with plywood, when used for roof construction, was due to the fact that there was a large amount of resonance caused by the movement of the wheels on the road, which tired the ear-drums of the passengers. Metal roofs were subject to the same rumble and it developed also that extreme heat would cause a slight expansion of the metal and allow the roof to rattle. Much experimenting is being done with different types of cushion spring construction. Curtain rollers have been improved, but locks, door bumpers, door strikers and the like, have not advanced to any great extent since the construction of automobiles began, although some slight improvements have been made.

I think that body construction will not be changed radically until either the basic type of design or shape is

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transformed or there is a firmer foundation to build upon. Today, all types and styles of body, from the two-passenger open-type to the seven-passenger enclosed-type bodies, are built upon the same foundation base. When we have different frames, and this will be only through evolution, much of the weight, rattle and noise of the enclosed automobile body will be eliminated.

THE DISCUSSION

E. W. M. BAILEY:—I wish to call the attention of automotive engineers, especially chassis men and the men who are not body builders, to the twisting effect of the chassis upon the body. I have had some experience in building automobile bodies, and I cannot see why any enclosed body does not go to pieces. I have had trouble with some that did go to pieces. In one case we insisted that the chassis maker use a deeper frame because the deflection was so great. There has been no real remedy suggested.

I ask automotive engineers, salesmen and automobile men generally, not to be too conventional. When the horseless carriages came out they were very unconventional. When the engineer came out with a new idea, it was accepted if it was right, no matter how it differed from the conventional. But, my father said that in the days of the coach and carriage builders they were not allowed to do unconventional things. Our American coach builders really copied the designs of the French and English, which were very heavy. No man was allowed to build a light coach body of the enclosed type. The buggy builder, however, designed a purely American vehicle and it was made to carry ten times the passenger or vehicle weight that the coach carried.

In enclosed body building the chassis must twist. This means that the body must give or else the body must help support the chassis. Both things happen in practice. If the chassis sill is bolted down throughout the whole length of the frame, it undoubtedly strengthens the frame to some extent.

Weight is a serious thing for the automotive engineer. These things are all related to each other. The weight of a limousine body might be as stated from 1500 to 2000 lb., but that is a little heavy according to my experience. Even 1200 or 1500 lb. is considerable weight to carry around. I have had experience with the electric automobile, where one could absolutely measure the power

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required to move the car. Our power was cheaper than gasoline, but we naturally wanted to economize it. With voltmeters and ammeters we could measure the power accurately. If a difference of 10 to 15 lb. would show in a 2000-lb. electric car as it did in our tests, it certainly affects the performance of a gasoline car.

In the matter of the chassis and the body twist, we must either arrange some kind of three-point suspension or a separate frame, so that the body need not carry the chassis frame; or, we must devise a construction so that the body can move with the chassis without wrenching itself. Either of those things is possible if we disregard conventional ideas. If an enclosed body were constructed in a very different way so that these things could be done, probably it would be termed a freak. The construction of the enclosed body is highly conventionalized. There are some 350 pieces of wood in the frame of a limousine. Every one of those pieces is named; the sill, the pillar, the rails, and even the minor pieces all have a name or are described by location. If a body is to be built as suggested, that conventional construction must be eliminated and I think it can be done.

In my electric car propositions, we made a phaeton body, an open phaeton like the horse-drawn phaetons that were very common at one time. We made a bentwood body that was 4 in. wider than any other and that weighed less than any of the others. It weighed less than 30 lb. and there was no other body that weighed less than 130 lb. If it could be done in that case, it can be done in the enclosed body through the use of laminated wood or plywood; not used as a covering over of the conventional frame, but with an entire change of the frame. My father was, I think, the pioneer in the use of laminated panels in vehicles, the first one being of basswood, with linen between. Previous to that he made rotary-cut panels with a band saw. He sawed a log endwise in a spiral curve to the center, and then steamed the product and straightened it out. By this method we could make much thicker panels. We could cut ½-in. panels and straighten them out without causing checks on the outside. We could use a hard wood such as ash, oak or walnut, and get out panels 40 ft. long and 4 ft. wide that were all quartered grain. I have used plywood a long time. If the body is designed to utilize the strength of the plywood rather than the frame and we are allowed to do some other unconventional things, I believe that the

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weight of the enclosed body can be reduced certainly 50 per cent. I think we could reduce its weight 60 per cent or even more. If we could eliminate 500 or 600 lb. of weight that the chassis must support, think what this would mean in improved car performance. If 100 lb. of weight will show in the power required to move an electric car, certainly a saving of 500 to 800 lb. is of value to automotive engineers in gasoline-propelled cars.

Regarding the curing of wood and the statement that a moisture content of 10 per cent is about the standard, Mr. Stone spoke about the effect of wood swelling and shrinking afterward when fastened. I have kiln-dried some millions of board feet of wood for bodies and have had most of the trouble with the wood in the factory. Some factory buildings are very dry. From the time the ground freezes until spring their atmosphere is absolutely dry. In the wholesale production of enclosed bodies it is necessary to pile up many thousands of pieces of body frame ahead of the bench worker who assembles the parts. If they were not very dry, that could not be done. I have dried most lumber down to 2 or 3 per cent of moisture content. With good apparatus and skilled men in charge of it the kilns will do that. Then we took the pieces into the shop and, after being band-sawed they would have time to come to the humidity of the factory. We never had any trouble on that score. For the benefit of body makers who work in smaller quantities, I would say that in the horse-drawn vehicle days, where we handled many thousands of pieces, we never kiln-dried a plank in our own factory. We blocked it out first to the rough dimensions, dried it almost to absolute dryness, brought it into the factory and let it rest there until it reached the humidity of the shop. It would do that in a week, in ordinary commercial quantities. You can dry a stick very much quicker and with less care than you can a plank or board. Band-sawed air-dried lumber can be dried successfully in a hot kiln; some moisture can be supplied if one pleases, but there is no apparent trouble from it at all in the small pieces. One cannot get case-hardening in a piece as small as a pillar; perhaps a sill would require some different treatment, but from a pillar down there is no trouble in drying ordinary quantities.

CHAIRMAN R. E. NORTHWAY:—It would appear that we must have either resilient bodies or three-point suspension frames.

P. E. STONE:—As to the weight of bodies, when I men-

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tioned 1500 or 2000 lb. to the body I meant the weight as ordinarily equipped, with chassis equipment, tools and passengers. I spoke of 2000 lb. because that is really the weight which the body stands. The average weight of an automobile enclosed body today will vary from 700 to 1200 lb. and possibly one make of body would weigh about 1300 lb. without passengers. The statement is true about drying lumber to sub-normal shop conditions. Dry the lumber too low and let it come up in moisture content, rather than begin with too much moisture and lower it in the shop. When lumber is shrinking it checks; when it is absorbing moisture it does not check. Many large body-building plants are introducing thermostatic control to take care of the humidity in the winter. This is true also in furniture shops.

I have had considerable experience in drying panels. Plywood, when using the glue spreader, should be dried to a moisture content of about 5 per cent before the glue is applied; say 3 to 5 per cent for the core and shell. When it is finished and comes out of the dry kiln for the last time it has from 8 to 15 per cent of moisture; my experience has been to keep the dry kiln below 100 deg. fahr. temperature for best results, because there is less internal strain in the cores. If the temperature is raised too much with low humidities, there is a certain expansion of the core, which is laid opposite the grain of the shell; lower temperatures and rapid circulation of air will give very good results. Thicker panels should not be taken out of the dry kilns until the temperature of the kiln and the plywood has come down to that of the room.

Great trouble is experienced with veneer in roof construction. Formerly there were more veneer than plywood roofs. The shell and core were of different thicknesses in the old automobile body roofs. Several years ago when the dome shapes with sweeps from front to back began to be used, roofs were manufactured only by one or two companies in the United States who used a mold and built the plywood up to fit the double curvature from front to back with the proper sweep. These roofs came practically to shape; otherwise checking would have resulted. We covered these roofs with canvas and painted them. The great trouble with plywood in automobile body construction is to moisture-proof both sides. If it is treated with anything to keep the moisture out, a good glue joint cannot be obtained. That is the only difficulty

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with plywood. If one can nail or screw it on, it is all right. But if a glue joint up against a pillar or something like that is wanted, there is difficulty in keeping the moisture away from both sides of the plywood. If the moisture gets at it, trouble results.

GLUES

WILLIAM J. BAIN:—The statement that ox blood and casein glues had to be used by experts, applied several years ago, but it is really not true today. Casein glues really gained their prestige in the war, as was true of many other things. Casein and blood albumen are about the oldest adhesives known and are not a new discovery as many people think today. Ask any old fellow that has served as an apprentice in Europe, if he has ever used a "pot-cheese glue" for gluing outside work. Very likely he will say he has. This pot-cheese glue was a casein glue.

When the casein glues were first introduced into this country, they were shipped to the manufacturers in two parts. The manufacturer received the prepared casein and the other ingredients, and was given a formula for their mixing. He had a man in the plant who did nothing but mix this casein glue. Generally this man prepared much more glue than was required for the work on hand, and as the glue would not stand up for more than 2 or 3 hr., he would have to throw away about 50 per cent of the mixture, causing a loss of both time and material. This was a great objection to the casein glues. But since then, the laboratories have been studying the problem, and they have now improved the casein glues so that the ordinary man in the shop can use them just as well as he uses the hide or other glues. About the beginning of the war the glue was put out in the form of a white powder; it was necessary only to add the proper proportion of water, agitate it for a few minutes and allow it to stand about 12 min. In about 15 min. after this powder is mixed with the water it is ready for use. It need not be used immediately, as the glue will stand in proper solution for about 12 hr. under ordinary conditions.

For all practical and commercial purposes the casein glues are waterproof and will stand up under any condition that they will encounter in the commercial line. An old foreman told me that he had used casein glue 40 years ago in Austria. He made tables that stood out in the

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open air in the Royal Gardens. Several years ago he went back there and found that those tables were just as good as the day they were made. Actual tests offer further proofs. Take a panel for instance, lay it up with casein glue, and allow it to dry for 48 hr. until the glue has arrived at its maximum set, and has attained its full waterproof qualities. The panel can then be boiled for 10 to 12 hr. and there will be absolutely no separation. It can be soaked in water indefinitely. I have soaked such panels until they have become green with mold. I could then twist such a panel into a spiral and there was no separation. A panel can be subjected to sufficient heat to char the wood, and the joints will not open up; in fact the joints are moisture-proof and heat-resistant at the same time.

For practical use in the factory the advantages of casein glue over other glues are numerous, in that they are waterproof and heat-resistant, and are more economical to use in every way, from both price standpoint and spreading capacity. It covers from 40 to 100 per cent greater space to the pound than hide glue. It is more easily prepared, being mixed cold and applied cold, and within 15 min. after mixing one can begin spreading the panels. There is no other glue on the market that can be prepared and used as quickly as this. Another feature is that the use of hot cauls and steam boxes is eliminated, and the glue room need only be kept at the regular temperature of the remainder of the factory, say about 70 deg. fahr., and proper gluing can be done and the desired results obtained.

Mr. Stone referred to molded plywood tops. I have seen such tops molded. These tops have been used for years. They were put together wih casein glue. Gluing operations in the factory did not have to be changed, except to eliminate heat as referred to before. The only special apparatus needed is a rotary mixer that will prepare the glue fast enough.

Various grades of casein glues are manufactured; there is a special grade for joint work, and another for veneer work. These special glues stay in solution for about 12 hr. A third grade used for veneer work is a glue that will take about 2½ lb. of water to every pound of glue; what is left at the end of the day is kept and mixed with the fresh batch next morning, so there is no loss. This is a new development since the war.

MR. STONE:—What is the rate of deterioration of the

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casein glues? What makes some casein glues soluble in water?

MR. BAIN:—The deterioration of casein glues is only relative, as glue mixed at 8:00 a. m. can be used until 6:00 p. m., but the next morning one would find an insoluble mess in the glue pot which greatly resembled a custard.

The glues on the market at present include vegetable, fish, hide, blood-albumen and casein glues. Hide, vegetable and fish glues set by the evaporation of the moisture that is in them. Humidity or dampness causes them to dissolve again because they are just dried by the evaporation of their moisture content, but undergo no chemical change. With casein glue, as soon as the powder and the water are put together, a chemical action begins. This chemical action is very perceptible within the first 15 min. of mixing. The original mixture looks very much like a cooked cereal. After 15 min. its nature changes, and it runs in a free flowing liquid, very smooth and very similar to a heavy cream. The chemical action continues until the glue is absolutely hard.

In contrast to the hide glues, the longer a casein glue joint endures, the harder it becomes. The casein glue joint is also stronger with increased age. We have proved this by laying aside joints for 3 or 4 years and breaking them on a testing machine, in comparison with joints 48 hr. to 6 weeks old. The older joints showed the higher percentage of strength.

MR. STONE:—Some casein glues are moisture-proof and some will dissolve the first time they are touched with water. What chemical action is lacking? Is it not true that one cannot be absolutely sure of the present casein glues?

MR. BAIN:—I can speak only from the standpoint of one casein glue that I have worked with and tested. I have samples that I have baked, boiled, soaked in cold water and all that. I cannot detect an opening on the joint. When I say that the casein glue I am talking about is absolutely waterproof, I mean that it is highly water-resistant for commercial purposes; that is, if a panel is glued up and left to dry for 48 hr., it will not come apart within 2 or 3 hr. after being thrown into a tank of water, and will also undergo any of the tests mentioned before.

MR. STONE:—Are you sure that every batch of casein glue will be equal and alike?

MR. BAIN:—The firm I refer to has been manufactur-

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ing waterproof glue for 20 years. It manufactures its own casein, and has a laboratory in which everything that goes through for use in the glue is carefully watched and tested. Being manufactured according to a chemical formula, the casein glues are as consistent as they possibly can be, and can be depended upon. This consistency has been found in shipments of casein glues, which cannot be said of hide or other glues. As to what makes some casein glues water-resistant and others not, that is a matter of chemistry and I do not know.

Casein waterproof glues when used in conjunction with plywood for automobile construction, will bring the cost down to a practical figure, and will tend to eliminate the shrinking and opening up of the joints, and can be used with a greater margin of safety on panel work, than vegetable or other glues. The blood-albumen glue panels are more waterproof than those of casein glue, but are high in relative cost, and are almost prohibitive for exclusive use in general body building.

Regarding the length of panels and the size of panels that can be rotary cut, this work is limited only by the length of the lathe and the thickness of the log. I have seen an oak log peeled, and the veneer ran off fully 125 ft. in length. This sheet was broken into 25-ft. lengths, and these laid over one another. They were then carried on an automatic conveyor to the slicer, where they were cut to the size of the panel desired.

MR. BAILEY:—To automobile body builders, this matter of slightly more or less waterproofness of glue is splitting it too fine. I can find sleighs with laminated panels made with hide glue that have been in use for 30 years and that are all standing up. Bodies are painted inside and out. If they are not so painted a waterproof glue is better, but if they are properly painted they will stand up anyway. We have glued thousands of panels with hide glue, using no screws or other fastening, and in quantities of them 10 years old the panels are not warped.

MR. STONE:—When I first started to build automobile bodies we were making them entirely of wood. We thought we could not make a back with a side panel and not have a molded covered joint. We have found out that this can be done. It was done with hide glues and on exposed joints; those hide glue joints are still standing up.

MR. BAILEY:—Is that under a good paint?

MR. STONE:—Yes.

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CHAIRMAN NORTHWAY:—We need more definite information as to how to design and construct automobile bodies to meet road conditions and lighten the weight of the car.

C. H. METZ:—The problem is how to combine the body with the chassis. The two features which must be considered are the deflection of the frame member owing to the weight and strain placed upon it, and the twist that it is subject to on account of the unevenness of the road surface. I think it is not possible or desirable to build a frame sufficiently rigid so that all the twist can be eliminated. We eliminate the deflection caused by the weight, by building the frame section much deeper. I think the tendency is in that direction. A number of cars are being built now with frame sides 8 to 10 in. deep, which takes care of that situation very effectively.

The twist in the frame is a considerable problem and I think the frame is not the only member that must be considered in solving it. The tires take care of it to some extent. That matter is being solved in the right direction by using larger tires and ones that are more flexible. Tires are depressed by the amount of weight that is placed on them. An unevenness in the road causes the tire that goes into it to be relieved of some of the weight and the tire on the opposite side has an extra burden. Some of that unevenness is taken care of by the tire. Another member that takes care of more of this unevenness is the spring. Unfortunately, springs do not have a sufficient horizontal range to take care of all of the unevenness. There is opportunity for an improvement in springs, so that when one wheel goes into a hole the part that the tire cannot take care of will be taken care of to a considerable extent by the spring. In an extreme case, the frame will have to be flexible to some extent to take care of more of it. I believe we never will be able to pass it all along to the chassis. The body will have to carry some of the burden, and I think bodies will need to be made more flexible. If they are made lighter, they necessarily will become more flexible.

In considering this problem we must take all of these features into consideration. We should not attempt to remedy it by requiring any one feature to take care of all the mistakes. Our experience has been mostly with open bodies. We have built open bodies with the idea of taking care of a considerable portion of the twist in the body and have been fairly successful. In the line of en-

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closed bodies, with longer doors and the roof to take into consideration, they will have to be made flexible to a greater extent than has been true heretofore.

CHAIRMAN NORTHWAY:—We must consider the car as a whole. While we may have to come to having the body and chassis built as a unit, that does not work out as a good manufacturing proposition. Some of the best ideas in the world cannot be put into such shape that they can be successfully manufactured. We must look at car building not only from the point of designing but from the point of meeting the customer's approval and making a profit.

E. A. ROBBINS:—There are two examples of cars in which it appears that the designer has done something to take care of the twist. In the Ford car the frame is suspended from both ends, and the new Overland car is practically suspended from the front and the rear. Regarding deflection of the frame, I have a Ford car with a triangular body brace in front and a coupe body. When starting up a steep hill it buckles just at the front of the body. The hood vibrates up and down fully ½ in.

R. J. S. PIGOTT:—Considering the difficulties in overcoming the inherent strains in the body that are due to the rack or weaving of the chassis, it would appear that perhaps we are not paying sufficient attention to the design of the enclosed body as a box-girder whose joints are sufficiently stiff so that the structure acts as a unit rather than as a number of jointed members. As an instance of treatment of bodies in this manner, a more or less parallel case may be taken from railroad and trolley-car design. A few years ago, Mr. Stillwell devised a body construction for heavy electric interurban cars, which treated the whole body as a box-girder and practically eliminated heavy members such as sills and bolsters. The design of the one-man safety-car has accomplished further progress along this line, since the body is used entirely as a chassis and there are practically no longitudinal channel members acting as a frame. The side wall of the car is treated as a deep girder. This is especially true in some of the latest designs, involving the extensive use of automobile materials and methods. It seems easily possible to not only average up the amount of distortion over the whole of the body, by making it act as a unit, but also reduce the weight very considerably.

Designers of automobile bodies must face the situation

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that no chassis, however stiff, can entirely eliminate weaving. Moreover, in a light-weight car, it will probably be extremely undesirable to eliminate entirely the effect of spring yield in the chassis. Therefore, the body designer is faced with two alternatives, either to suspend the body from three points or to design it so that its distortion will be equally divided at all places, such as the joints around the door openings and the cowl.

W. F. EADE:—In designing a car, the air head-resistance should be considered in connection with the power required. If the car is of such a shape that the head-resistance has been decreased to a minimum then the power required to drive the car can be reduced and a large heavy engine is not needed. The engine power required to overcome air resistance varies as the square of the speed, and one can readily see that a poorly designed car will consume more power merely to overcome air resistance and have less power left for tractive effort.

MR. ROBBINS:—Regarding streamline design for bodies of cars, I think we are not operating them ordinarily at high enough speed so that the form of the body has much to do with the air resistance.

MR. BAILEY:—The wind resistance increases as the square of the relative velocity. At 20 m.p.h. it runs into a lot of power against a 20-mile wind or at 30 m.p.h. against a 10-mile wind.

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